PRECISION OF TIDAL DATUMS IN THE SACRAMENTO RIVER, CALIFORNIA

Timothy Alan Bouquet

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

PRECISION OF TIDAL DATUMS IN THE
SACRAMENTO RIVER, CALIFORNIA

by

Timothy Alan Bouquet

June 1980

Thesis Advisor: W. C. Thompson

Prepared for: National Ocean Survey (Code C33)
6001 Executive Boulevard
Rockville, Maryland 20852

NAVAL POSTGRADUATE SCHOOL
Monterey, California

Rear Admiral J. J. Ekelund
Superintendent

Jack R. Borsting
Provost

This thesis was prepared in conjunction with research supported by the National Ocean Survey (Code C33), 6001 Executive Boulevard, Rockville, Maryland 20852 under Purchase Order No. NA80AAG02672.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NPS68-80-007	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Precision of Tidal Datums in the Sacramento River, California		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; June 1980
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Timothy Alan Bouquet		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NOAA Purchase Order NA80AAG02672
11. CONTROLLING OFFICE NAME AND ADDRESS National Ocean Survey (Code C33) 6001 Executive Boulevard Rockville, Maryland 20852		12. REPORT DATE June 1980
		13. NUMBER OF PAGES 182
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Naval Postgraduate School Monterey, California 93940		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Estuary Tides
Sacramento River
Comparison of Simultaneous Observations
Tidal Datums
Tidal Epoch 1960-1978

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A method is developed for extending computed 19-year tidal datums (1960-1978 epoch) throughout the ocean/river transition zone of the Sacramento River System using water-level measurements from two long-term reference stations, at San Francisco and Sacramento, and collected over an 18-month period at seven secondary tide measuring stations located throughout the transition zone. The method uses the standard procedure of the National Ocean Survey for comparison of simultaneous observations

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
(Page 1) S/N 0102-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

to determine 19-year tidal characteristics as a function of river level, from which are determined the 19-year datums. The accuracy of tidal datums, indicated by the standard deviation, is found to be within 0.1 foot in the lower bay system and within 0.2 foot upriver.

Precision of Tidal Datums in the Sacramento River, California

by

Timothy Alan Bouquet
Cartographer, Defense Mapping Agency
B.A., California State University Northridge, 1974

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY (HYDROGRAPHY)

from the

NAVAL POSTGRADUATE SCHOOL
June 1980

ABSTRACT

A method is developed for extending computed 19-year tidal datums (1960-1978 epoch) throughout the ocean/river transition zone of the Sacramento River System using water-level measurements from two long-term reference stations, at San Francisco and Sacramento, and collected over an 18-month period at seven secondary tide measuring stations located throughout the transition zone. The method uses the standard procedure of the National Ocean Survey for comparison of simultaneous observations to determine 19-year tidal characteristics as a function of river level, from which are determined the 19-year datums. The accuracy of tidal datums, indicated by the standard deviation, is found to be within 0.1 foot in the lower bay system and within 0.2 foot upriver.

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

Figure Page

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Dr. Warren C. Thompson for his guidance and counsel in the preparation of this thesis and making useful comments. Most aspects of this thesis are the result of close collaboration between Dr. Thompson and the author, including the basic analysis procedure and the definition and interpretation of datum planes in the riverine and transition zones.

The assistance of Mr. James R. Hubbard, Mr. Howard V. Krishner, and Mr. Jack E. Fancher of the National Ocean Survey and Mr. R. M. Oltmann of the U.S. Geological Survey in the timely procurement and transmission of data is gratefully recognized. The timely assistance of Duffy Tegtmeier of the Naval Postgraduate School in the key-punching of the Sacramento data is truly appreciated.

Special appreciation is given to my loving wife whose understanding and patience enabled me to complete the necessary research.

I. INTRODUCTION

A tidal datum is a plane of reference for elevations determined from measurements of the rise and fall of the tides. Water depths and tide heights are referenced to these datums. High-water datums are used in the United States for the determination of property boundaries. A low-water datum is used for nautical charting so that actual depths will normally be greater than those charted. In areas of gradually sloping shoreline, the shoreline position can vary dramatically with the choice of reference datum.

In tidal rivers, such as the Sacramento River of California, the distance the measurable tide reaches upriver varies inversely with the river stage. At upriver stations the tides vanish at high river levels. On the navigable rivers draining the Atlantic slope of the Appalachian Mountains, the upriver limit of the ocean tides is a well-defined physiographic boundary known regionally as the fall line. On the Sacramento River, on the other hand, there is no convenient natural upriver barrier to the tides. The National Ocean Survey (NOS) is the responsible agency of the U.S. Government for tide prediction, nautical charting, and tidal-datum determination in domestic waters. They are presented in the Sacramento River, and many other rivers as well, with the problem of how far up the river system to

carry tide guaging for the purpose of tidal datum determination. This study investigates that problem.

The Sacramento River was chosen for study because of the availability of tide data collected over a common time period at a large number of tide stations in the river delta and the San Francisco Bay System by a cooperative California/National Ocean Survey tide program conducted in 1977-1979. NOS is planning both a coastal mapping program and a complete hydrographic survey of the San Francisco Bay and its tributaries as a part of their intensive investigation in the San Francisco Bay System.

This study does not directly answer the question of how far gauging should be carried up the river system, that being a policy decision to be made by NOS, but presents information that might serve as a basis for making such a decision. Data on tidal characteristics and on the quality of tidal datums in the Sacramento River are presented to provide this basis. The results may serve as a guide to the solution of tidal datum surfaces in other tidal rivers as well. Primary questions addressed include: (1) How do tidal characteristics vary with superelevation of the river (the height of the river surface above sea level), (2) with what accuracy can tidal datums be determined in the river system from a short series of observations, and (3) what quantitative criteria might be used to decide whether the river should be judged

tidal, or not, for the purpose of datum-plane determination? The focus of the analysis is primarily on question (2). This question is examined by computing equvalent 19-year tidal datums using a short series of tide observations at secondary tide stations in the river system, derived from comparison of simultaneous observations at an oceanic reference tide station having a long tidal history. The standard procedure for comparison of simultaneous observations used by NOS [Marmer, 1951] was used as a basis for datum analysis in the Sacramento River.

This study will in effect develop 19-year datums and ranges from a series of short observations for tide stations in the Sacramento River above Presidio, San Francisco to Sacramento, and then analyze the accuracy of these determined datums. This will be done using raw hourly heights by first separating the dominant harmonic tidal components from the non-harmonic river fluctuations. Then the heights and times of high and low waters at the secondary tide stations will be computed for comparison with the same tides at Presidio to determine the 19-year datums and ranges using the standard procedure. A least-squares technique will then be used to define relationships between river levels and computed tidal datums and ranges. The variability of the determined datums represents the accuracy of datum determination by the standard procedure for comparison of simultaneous observation in the Sacramento River System.

II. LOWER SACRAMENTO RIVER SYSTEM

The Sacramento River System considered in this investigation extends approximately from the City of Sacramento, down the main channel of the Sacramento River to Suisun Bay, thence along the tidal channel that runs through Suisun and San Pablo Bays of the San Francisco Bay system to terminate at the Presidio tide guage in the entrance to the San Francisco Bay (Figure 1). Sacramento is located near the upper limit of tidal influence. Presidio, on the other hand, is considered here to be situated in an oceanic tidal environment where daily water-level variations are primarily tidal in nature. Between these two stations lies the tide-river transition zone which upriver is subject in diminishing degrees to the influence of the tides and in increasing degrees to the influence of the river. Between the City of Sacramento and Suisun Bay the river traverses the delta of the Sacramento, San Joaquin, and several smaller rivers. Water levels in the Sacramento River below the confluence of the San Joaquin River near Collinsville often reflect runoff from both major rivers, but above Collinsville the river level is determined mainly by runoff of the Sacramento.

Nine tide observation stations in the Sacramento River System were chosen for analysis in order to present a picture of the tidal and river characteristics throughout the

tide-river transition zone (Table 1). These stations were selected for their even distribution along the river system, and to represent each tidal regime along the river system. The Sacramento River at Sacramento, at a distance of about 111 nautical miles (NM) upriver from San Francisco, is about 200 yards wide, and has a charted depth of about 10 feet (low river stage). At Walnut Grove, downriver 28 NM and below several meanders, the river is even narrower (about 100 yards wide) and about the same depth. At Three Mile Slough the river widens to half a mile and is over 20 feet in depth. Further down, the San Joaquin joins the Sacramento as it empties into Suisun Bay. Collinsville is located at this juncture. Mallard Island is 4 NM westward of this point and exhibits similar tides to those at Collinsville. Suisun Bay widens considerably (to 5 NM) and narrows again at Benicia, which is at the eastern entrance to Carquinez Strait. This strait is a constricted channel cut through rolling hills that connects Suisun Bay with San Pablo Bay to the west. Port Orient is located in the southern portion of San Pablo Bay, just 10 NM north of San Francisco. The long-term primary tide station used for comparisons in this study is the gauge at Presidio, San Francisco.

This river system presents several interesting features for tidal studies. These include the extensive lower bay system in immediate and open communication with the Pacific

Ocean through the Golden Gate, the constriction of Carquinez Strait, the upper bay system comprising mainly Suisun Bay, and upstream from that the delta region where the tide wave is divided among numerous tributaries and sloughs.

To relate the datums throughout the river system, all measurements and datums were reduced to the National Geodetic Vertical Datum (NGVD), which is the standard geodetic reference datum for elevations in the United States. Tide-staff elevations relative to NGVD are given in Table 2. There is a possibility of subsidence in the Sacramento River Delta. The most recent geodetic leveling in the delta was carried out in 1964 and 1965. No attempt was made in this study to determine or account for subsidence.

Annual variations of river level at Sacramento are so great as to eliminate any tidal influence during periods of high water. Figures 2A and 2B show twenty years of mean monthly water levels at Sacramento, 1958-1978 [Zeile, 1979]. Winter water levels above 20 feet can be seen in some of the prominent winter peaks. Summer lows are usually, but not always, below five feet NGVD. Note in Figure 2B the "drought years" of 1976 and 1977 when the winter water levels were lower than the average summer lows. Table 3 which includes statistics for Sacramento is a primary product of this study. Mean river levels at Sacramento for the 18-month period of this study were statistically typical for the river over many

years, as can be seen from a comparison with the monthly mean river level for the 19-year period 1960-1978 (Table 3). Extreme variability of the river during the study period was not as great as is sometimes found during the previous 19 years.

III. TIDAL DATUMS AND RANGES

Two high waters and two low waters each day characterize the semi-diurnal mixed tides which are found on the Pacific coast of the United States. The two high and two low tides are normally of different heights, thereby providing a higher high water (HHW), a lower high water (LHW), a higher low water (HLW) and a lower low water (LLW) each day. The sequence of these four water levels varies throughout the fortnightly tide cycle. Every 14 days the tides go through a cycle of both reduced range (neap tides) and increased range (spring tides) due to changes in phase of the primary lunar and solar harmonic tidal constituents. Arithmetic means of these water levels over any chosen observation period produce four primary tidal datums, MHHW, MLHW, MHLW, and MLLW. From these are derived the following tidal datums which are the datums used in navigation and in property boundary determinations: (1) mean high water, MHW, which is one half of the sum of the MHHW and the MLHW, (2) mean low water, MLW, which is similarly the mean of the MHLW and the MLLW, and (3) mean tide level, MTL, the mean of the MHW and MLW [Marmer, 1951]. These datums are listed in Table 4.

Mean sea level, MSL, is derived from the mean of hourly heights rather than from water level extremum values. In this study it was computed only for Presidio for inclusion

in Table 5. The terminology mean river level, MRL, is used interchangeably with mean tide level, MTL, for stations upriver where the tidal influence is greatly reduced, their mathematical derivations being the same.

Tidal ranges are a measure of the mean amplitude of the tide and are derived from differences in elevation of the tidal datums. The mean range, MN, is the difference between the MHW and the MLW. The height difference between the MHHW and the MHW is the diurnal high inequality, DHQ. Similarly, the difference between the MLW and the MLLW is the diurnal low inequality, DLQ. The diurnal or greater range, GR, is the height difference between the MHHW and the MLLW.

By computing tidal datums from observations over a 19-year period, termed a tidal epoch, virtually all significant astronomical cycles can be averaged out, thereby providing datums which, in the absence of eustatic sea level or land elevation changes, are stable. The period of the longest tidal constituent of significance, caused by regression of the moon's nodes, is 18.6 years, but 19 years is used in practice to average out the larger amplitude yearly tide cycle. Because of long-term variations in sea level, it is necessary to specify the 19-year epoch used for computing datums. The 1960-1978 epoch, which NOS intends to adopt as a replacement for the 1941-1959 epoch [Hicks, 1980], is used as the reference for the datums and ranges presented in this study.

The elevations of the tidal datums and ranges for the epoch 1960-1978 at Presidio, San Francisco, which were used as the standard for comparison with the secondary stations in the Sacramento River system are given in Table 5. Included in Table 5 are the elevations of the previous epoch of 1941-1959 used in other studies, and the datums for the 18-month period of this study.

IV. DATA AND EDITING

The tide observations analyzed in this study were acquired on magnetic tape, tide gauge analog record, and paper computer printout from NOS and the U.S. Geological Survey (USGS). These are listed in Table 2. Digital tide data for Presidio for January and February 1978 were unavailable, so heights of high and low waters were read directly off the analog bubbler gauge record supplied by NOS; for these two months the times of the predicted tides were considered adequate since they do not affect datum determination by the comparison of simultaneous observations procedure. Hourly heights were extracted from both the 15-minute computer printout supplied by USGS and the six-minute magnetic tapes supplied by NOS for systematic computer handling. These hourly heights were used to compute, by a procedure described later, the times and heights of high and low waters, which in turn were used to compute 19-year datums and ranges by the method of comparison of simultaneous observations. Tide data for Hercules was not analyzed due to the limited amount of data available.

Due to equipment malfunctions, gaps occurred in all of the tide records (Table 2). Short gaps in the record of up to three days were interpolated to within 0.1 foot by using the pattern of the previous and subsequent tides as a guide.

Here, ten days of hourly heights were plotted on the same 48-hour graph as five lines centered around the gap. The missing tides were then interpolated by hand to best fit the pattern. Gaps longer than three days could not be interpolated with acceptable certainty. Mallard Island, Collinsville, Three Mile Slough, and Walnut Grove contained uneditable gaps, requiring special handling in computations. All datum and range computations were performed for the whole study period of 1/1/78 - 6/30/79 except for the uneditable gaps.

V. PROCEDURES AND ANALYSIS

Programs described here extract the tidal component from the edited hourly heights, determine the heights and times of high and low waters, sort these tides by daily type, and then determine tidal datums by the comparison of simultaneous observations procedure. This procedure compares the same tides at a short-term or secondary station with a long-term reference or standard station. Graphical presentations and analysis of these extended 19-year datums for the 1960-1978 epoch were then produced. The important programs are included in the Appendix. All computations were performed on the IBM 360 digital computer at the W. R. Church Computer Center of the Naval Postgraduate School. Graphics were produced on the Versatec plotter attached to the computer.

A. HIGH AND LOW WATERS PROGRAM

For the purpose of computing datums by the procedure of comparison of simultaneous observations, the times and heights of high and low waters are required. To obtain these values from the digital hourly height data, a second-degree polynomial was fitted using a least-squares procedure to the hourly heights. This parabola-fitting procedure, which is fully described by Zeile [1979], consists of two steps. First, four successive hourly heights are scanned in a moving

window for a trend or slope. Whenever these heights show a change in the sign of the differences in successive hourly heights, this is used as an initial guess for an extreme water. Upon detection of a change in trend, the five hourly heights distributed around the sign change are then fitted with a polynomial. The point on the curve with a zero derivative is then used as the time and height of the extreme water. This procedure provides heights accurate within a tenth of a foot. For a more refined determination of the tide time and height upriver where the tide wave is clearly assymetrical, a third or fourth order polynomial might be more appropriate for some purposes. This refinement is not justified here in view of the fact that variations in river height greatly exceed the accuracy with which tide heights can be determined.

B. TIDE SELECTION AT PRESIDIO

In order to determine tidal datums the tides must be sorted by daily tide type. Since all river stations were compared with the Presidio reference station, all tides at Presidio were indexed by daily tide type. It is normally a simple task to distinguish the higher high, lower high, higher low, and lower low waters by their relative heights. When two consecutive high or low waters have the same height, it is adequate to follow the previous day's pattern.

Since the average period between consecutive tides is a little longer than six hours, every fortnight there occurs a

solar day containing only three tides. For accurate datum determination it is essential that the tide type of the three tides be determined. The Manual of Tide Observations [USCGS, 1965, p. 54] recommends for hand comparison that the previous day's tide pattern be used for a guide to the pattern for the three-tide day. This procedure usually works well, but is inadequate on those occasions when a change in tide type sequence occurs simultaneously with a three-tide day. Attempts to use the previous day as a guide sometimes failed early in this study because the day-to-day change in tide height is occasionally greater than the diurnal high or low inequality. A satisfactory solution, developed by the author, is to use the relative heights of the four waters occurring before noon on the day of the three-tide day as a guide for the tide or tides in the A.M. and the subsequent four waters as a guide for the water or waters occurring in the P.M. This identifies tide types in a consistent manner.

C. HARMONIC FILTERING PROGRAMS

During high river levels at upriver stations the range of the tide may be reduced to approximately the level of noise, which has a magnitude of about a tenth of a foot [Zeile, 1979]. The river height at which tides can be identified at a given station can be increased by separating the prominent semi-diurnal and diurnal tidal components from the non-harmonic river components of the water level. This

was done by computing running means of the hourly heights using averaging intervals determined by the periods of the harmonic components to be suppressed, i.e., 24 hours for the solar component and 25 hours for the principal lunar component ($2M_2$ = 24.96 hours). Application of these filters applied singly and in combination is illustrated in Figure 3 for a 24-day series of tide measurements at Presidio. The upper two curves, displaced vertically for ease of comparison, show the residual water level remaining after application of the 25-hour filter (upper curve) and the 24-hour filter (lower curve). The middle set of curves shows the effect of double filtering with both 24 and 25-hour running mean filters and the triple filter recommended by Godin [1966], compared with the 24-hour filter. It may be seen in this example that the double filter eliminates these harmonic components almost as effectively as the triple filter. Use of the triple filter, which requires a little more computing time, yields only an incremental improvement over the double filter; accordingly, a double filter was used in this study. The residual, which at river stations represents the river component of the observed water level history, can then be subtracted from the hourly heights to extract the tidal component to be used in the comparison of simultaneous observations. This procedure was used for the uppermost river stations, Walnut Grove and Sacramento, because they both

experienced high enough water levels so that the tide would get lost among the noise.

An additional filter was used to eliminate fictitious tides (non-tidal water-level fluctuations mistaken for tides) occurring at Sacramento during periods of high river level. Zeile [1979] found that an actual tide wave would not arrive at Sacramento sooner than 6.5 or later than 14.5 hours after it passed Presidio. Accordingly, the time of tide at Sacramento was compared to that at Presidio, and if the lag was less than 6.5 hours it was considered fictitious and ignored. If the lag was greater than 14.5 hours it was assumed there was a missed tide; accordingly, the tide was nevertheless used as an estimate of the missing tide and also for the next comparison. This crude method produces an acceptable approximation of the mean river level, but other datums and ranges derived at river levels above tidal influence have no significance.

For the lower river stations, where fictitious and missing tides did not occur, the time lag from when the wave passed Presidio to the time it arrived at the secondary station was used to synchronize the array of high and low waters at the river station with the corresponding waters at the standard station. Travel times used were from the Tide Tables [NOS, 1978].

D. COMPARISON OF SIMULTANEOUS OBSERVATIONS PROGRAM

Tide observations at all river stations were compared to those at Presidio, San Francisco using the standard comparison of simultaneous observations procedure which is explained in detail by Marmer (1951). Two assumptions are made in the use of this procedure: (1) The difference between the mean tide level over the period of observation and the actual 19-year mean tide level is the same at both the standard and subordinate stations, and (2) the ratios of the observed ranges to the actual 19-year ranges are the same for both stations.

This procedure, which may best be understood from examination of the program given in the Appendix, first separates the tides by type (HHW, LHW, HLW, and LLW) at both stations. The mean of each tide type at the secondary station is then computed for the comparison period. Differences in height between the same tide at the reference and secondary stations are averaged over the comparison interval yielding mean differences for each tide type. The time differences in the occurrence of common tides at the two stations are used to compute the high water and low water time lags between the two stations. The elevations of the datum planes and the ranges as described in Table 4 are then computed for the period of the common tide observations for both stations. Range ratios are computed using the differences in the common

datum elevations between the stations and the ranges at the secondary station. These are then multiplied by the 19-year epoch ranges for the Presidio reference station (given in Table 5) to derive effective 19-year ranges (1960-1978 epoch) for the subordinate station.

The mean tide level over the observation period for the secondary station is adjusted to an effective 19-year mean tide level by applying the difference between the observed mean tide level and the established 19-year mean tide level at Presidio to the observed mean tide level at the secondary station. Effective 19-year high and low water datums are then computed from the effective 19-year mean tide level and the 19-year ranges.

E. STATISTICAL ANALYSIS AND GRAPHICS PLOTTING

Numerous customized computer programs were written to produce the many statistical data analyses and graphics presented in this report. None are included in the Appendix. The principal products include the following:

1. Time Series Graphs

Continuous 19-year datums and ranges were generated and plotted for each river station by the comparison of simultaneous observations procedure using a running 28-day observation period and a one-day computation step. Examples of these time series graphs, which show the seasonal

variability of these datums and ranges, appear in Figures 11 and 12 for Sacramento. Similar Graphs for all the river stations are included in Appendix A.

2. Datums and Ranges along the River System

To show the extreme values found in the data during the study period, a maximum, or peak, and a minimum were computed for each data set, and are included in Tables 11-19. Differences between these extreme values are listed in Table 9. Mean values were computed for each data set over the 18-month study period and these are included in Table 6, and plotted for the length of the river in Figure 5. High water and low water values from the 18-month study period are provided for each 19-year datum and range at each station (Tables 7 and 8). These statistics are also plotted for the length of the river system from Presidio to Sacramento (Figures 7-10).

3. Scatter Plots and Regression Lines

The 19-year datums and ranges were also plotted against the 28-day mean tide level for each station and are in Appendix A. For an example of one of these scatter plots, see Figure 15. A least-squares procedure was used to fit a straight line of regression to each data set, providing a mathematical relationship between the 28-day river level at each station and the computed 19-year datums and ranges. The standard deviation of each data set about the line of regression was also computed to provide a measure of the variability of each

relationship. The slope and y-intercept of the lines of regression were tabulated and are included in Tables 11-15 and 18. Graphs of these statistics along the river system for each datum and range are included in Figures 16-24.

4. Datums and Ranges at Presidio

In order to illustrate the effects and variability produced on datums and ranges by the use of various observation periods, tidal datums and ranges for Presidio for the study period were computed and plotted using simple running means of the various sample lengths (Figures 13-14, 26-31). Mean datums and ranges computed for the entire study period at Presidio are shown in Table 5.

5. Comparison of Observation Intervals

To demonstrate the accuracy of datum determination with various short lengths of comparison, 19-year datums and ranges were computed using 7, 14, 28, and 56-day observation periods at Sacramento. Time series graphs of these are found in Figures 11-12 and 32-37. Scatter graphs of these datums and ranges against mean river level for each observation period at Sacramento are found in Appendix A; an example is shown in Figure 38. Regression statistics for the scatter graph data are found in Tables 16-19, and are plotted against the length of comparison in Figures 39-47.

VI. DISCUSSION

A. TIDAL BEHAVIOR IN THE RIVER SYSTEM

Many of the characteristic features of tidal behavior in the river system are illustrated in Figure 4, which shows a short series of tide waves as they move upriver from San Francisco Bay during a period of high river stage. Simultaneous hourly heights for a two-day period are plotted for eight stations from Presidio to Walnut Grove. The curve for Sacramento is omitted, the mean river level being over 21 feet on these days and there being effectively no tides. The figure shows that as tide waves travel upriver, their range generally decreases and they arrive at each consecutive station at a later time. Less obvious in this example is asymmetry of the tide wave which develops upriver, the high tide traveling faster than the low. One can also see the increase in mean tide level upriver, the gradient of which is determined by the prevailing river stage. It may be noted that the MTL gradient increases markedly upriver from Three Mile Slough where the Sacramento River is confined to a narrow leveed channel. The increase in MTL can also be seen in Figure 5, which shows the elevation relative to NGVD of the derived 19-year datums throughout the river system (discussed more fully below). Note in this figure that MLLW

lies below MTL at the Presidio as far as 70 NM upriver from the Presidio.

Another interesting phenomenon is the increase in tide range found at some of the lower river stations relative to the range found at Presidio. According to the Admiralty Tidal Handbook [1975], as a tide wave moves into a typical estuary, the range is amplified due to its confinement in a narrowing channel. This increase exhibited in the Sacramento River System can be seen in the increased mean tide range shown in Figure 6 at Point Orient. Note also a second increase in range found at Three Mile Slough (56 NM from Presidio). This apparent increase is due to the lack of low water (summer) data for the lower two stations, Collinsville and Mallard Island. Above Point Orient, Figures 5 and 6 both nicely show the decrease in range which is generally observed as the tide wave opposes the river current and gains in elevation. Tidal influence is found at elevations more than double the MHHW level at Presidio, demonstrating that the tidal energy indeed climbs uphill. The DLQ is reduced substantially, whereas the DHQ is only slightly affected upriver by the increase in elevation. The data for Figure 5 and 6 are found in Table 6.

Figures 7 and 8 (and Table 7) show the 19-year tidal datums and tidal ranges, derived from 28-day comparisons, that correspond to a time of lowest river level during the

study period when the tide reaches the farthest upriver. At these times the computed 19-year datum elevations are lowest and tide ranges are largest. Figure 7 shows a slight upriver decrease in elevation of MTL between Point Orient and Benicia and also between Three Mile Slough and Walnut Grove. Subsidence may be a factor at Three Mile Slough; however, a comparison of MTL in Figures 5, 7, and 9 suggests that subsidence said to be occurring in the Sacramento-San Joaquin Delta has been small. This elevation discrepancy may be entirely due to the lack of data for Three Mile Slough during the low water summer months.

Figures 9 and 10 (and Table 8) show the computed 19-year tidal datums and tidal ranges along the Sacramento River System, derived from 28-day comparisons, that roughly correspond to the highest water stage in the river system during the study period. The decrease in tidal ranges upriver is relatively rapid and there is essentially no tidal influence at Sacramento. The diurnal high and low water inequalities are seen to disappear upriver so that the tides tend to become semi-diurnal in type. Note in Figure 9 the flat MTL in San Pablo Bay and in Suisun Bay, and the gradient found between Point Orient and Benicia. The latter is considered to be due to the constriction of the Carquinez Strait.

B. 19-YEAR DATUMS AND RANGES IN THE RIVER SYSTEM

The standard NOS procedure for comparison of simultaneous observations is used to carry datums from a standard or primary tide station at which long-term 19-year datums have been established, to a secondary or subordinate short-term station. This procedure is more accurate for longer periods of comparison than for short. The commonly used length of comparison is one month. This provides estimated 19-year datums having a standard deviation of 0.13 feet for oceanic tidal stations on the Pacific Coast within the same tide regime [Swanson, 1974]. Operational limitations have at times restricted tide observations to comparison intervals as short as a week or less, providing reduced accuracy. Because of the effect of length of comparison on accuracy of determination, a standard comparison period of 28 days was chosen for examining the effects of river superelevation on computed 19-year datums and ranges. A 28-day period was selected because it minimizes the prominent fortnightly cycle of spring/neap tides, it is the length of a lunar month, it approximates the commonly used comparison period of one month, and also is short enough for convenient computation.

In order to examine the effect of length of the comparison period on computed 19-year datums and ranges, computations were also made using a series of intervals of 7, 14, 28, and 56 days duration. This series provides a geometric

progression from a short to a longer comparison interval, including the 14-day interval which approximates the period of the prominent spring/neap cycle. Longer lengths of comparison did not provide a significant increase in accuracy over that given by the 56-day interval.

The results of these comparisons are discussed in Section B4.

1. Seasonal Datum and Range Variation

Upriver, the character of the tides varies considerably throughout the seasons. Figure 11 shows running 19-year datums at Sacramento derived from 28-day comparisons with the tides at Presidio using a one-day computational time step. Figure 12 shows the corresponding ranges. Range values shown for the periods of higher water level, above 10 feet NGVD, are essentially computational noise created by comparison of river flow fluctuations at Sacramento with real tides at Presidio. The values for the MTL do present an accurate picture of the mean water levels in the river. The largest 28-day greater range, which occurs at lowest river levels, is about a foot and a half.

Figures 13 and 14, which are presented here for comparison with Sacramento, show the variations in the datums and ranges, respectively, found at Presidio for the same period. These were produced by computing a simple running mean average of the appropriate high and low waters. The pips and

oscillations are computational artifacts resulting from the three-tide day, and occur with fortnightly frequency. Figure 13 shows fluctuations in the mean tide level which are primarily due to meteorological effects. The long-period harmonic fluctuations in tidal range, best shown in Figure 14, are attributed primarily to the annual and semi-annual harmonic components of the astronomical tidal forces. Similar graphs of datums and ranges were produced for 28-day comparisons for all the river stations and are included in Appendix A.

2. <u>Influence of River Flow on 19-Year Datums and Ranges</u>

Each 19-year datum and range was plotted against the 28-day mean tide level used to compute that datum and range for all of the river stations except Collinsville, and these graphs are included in Appendix A. Collinsville shows characteristics very similar to those at Mallard Island due to their proximity, and therefore has been excluded. With regard to terminology, mean river level is used interchangeably with mean tide level in places where the river flow is the major influence, even though both are computed from the mean of the high and low waters. These graphs are illuminating presentations of the range of 19-year values which would be expected from a comparison of simultaneous observations at each station knowing only the 28-day observed MTL. They also provide information on the variability of these datums and ranges with changes in river flow. The

circular patterns of data points exhibited in many of these graphs may be due to hydraulic differences between rising and falling river stages or to variations in contribution from the San Joaquin River.

In order to quantify the relationship between the 19-year datum or range and the observed 28-day MTL, a least-squares fit line of regression was computed for each data pair. The values for these are listed in Tables 11-15 and 18. The slopes given in the tables quantify the influence of the river flow on the datum or range shown. A zero slope indicates no river influence, a slope of one indicates no tidal influence, and a negative slope indicates an inverse relationship to river level. The significance of the y-intercept can be illustrated by imagining a cessation of river flow into the system. The mean water level of the entire system will then fall to sea level, and tidal ranges and datums will be primarily influenced by the geometry of the lower river system. Assuming the relationships computed from this data can be extrapolated to this low water case, the y-intercepts provide estimates of extreme values for the datum or range at unusually low water levels.

At Walnut Grove, for example, there is a definite decrease in the range of the tide as the MTL increases; this can be seen for the period of study in Figure 15. The linear relationship GR = 3.848 - 0.396 MTL can be fitted to this

data with a standard deviation of a tenth of a foot (see also Table 15). The GR intercept indicates that the largest 28-day diurnal range that could be expected at Walnut Grove is about 3.8 feet. The MTL intercept (or x-axis intercept) provides an estimate of the water level at which there will be no tide. This calculates to 9.7 feet NGVD. The equation also gives the level at which the tide range equals the tenth of a foot noise level as 9.5 feet NGVD. These values are close to the river level at which the tide disappears also at Sacramento.

Figures 16 through 24 show how these regression variables for the period of study vary along the river system for the five datums and four ranges of interest computed using 28-day observations. These graphs show the relative influence of the river flow and river system geometry on the datums and ranges along the river system. The reliability of these relationships is indicated by the standard deviation, plotted as squares. The degree of river level influence on the datums is indicated by the slope, plotted as triangles, with a zero slope indicating no river influence and a slope of one indicating no tidal influence. The influence of the geometry of the river system on the datums and ranges can be seen in the y-intercept values, plotted as circles, which are estimates for the 19-year datums or ranges which would be expected from a cessation of river flow.

Figures 16-20 show the variability of the 19-year MTL, MLLW, MLW, MHW, and MHHW datums from Presidio to Sacramento. The general increase of the slope upriver for all five datums clearly shows an upriver increase in the influence of river stage on the datums. Even in the lower bay system, the MTL and high water datums are influenced by river flow as is shown by the small positive slopes at Point Orient.

The standard deviation for all datums is lowest in the lower bay system (less than 0.1 foot), and generally increases upriver. It is 0.15 foot or less for all datums except for the low water datums at Sacramento, the latter being 0.18 foot. These small standard deviations indicate a very close relationship between datum elevations and the river level, and provide the basis for specifying a set of 19-year datum planes throughout the river system that are independent of the river level.

Nineteen-year high and low water datums are computed from the sum of a range and the 19-year mean tide level. Accordingly, the standard deviation of a high or low water datum will be equal to the root mean square of the standard deviation of the 19-year range and 19-year MTL. Any error in the computation of the 19-year MTL will contribute significantly to errors in computation of the high and low water datums; therefore, any improvement in the 19-year MTL determination in a river system will significantly improve the datum determinations.

Statistics on the 19-year ranges are shown in Figures 21 and 22. The slopes calculated for the greater range and mean range show similar patterns, increasing with increasing mean tide level (positive slope) till about halfway up the river system, where the superelevation causes a decrease in range (negative slope). There is a point about 60 NM upriver where the slope is zero, indicating that the ranges are independent of the river level. At Sacramento the slope again approaches zero due to the numerous water level data above the influence of the tides. A more negative slope value would be found at Sacramento if the regression was computed only for the low river levels which are subject to tidal influence. It is interesting to note that in the lower portions of the river system a tidal range amplification results with increases in mean tide level.

The effects of river flow on the inequalities are shown in Figures 23 and 24. The DHQ is little affected by the changes in river level, the slope of the statistical distribution being approximately zero regardless of river level throughout the river system. The variability of the 19-year DHQ averages less than 0.1 foot throughout the river system, and is about 0.02 foot everywhere below the narrow channel sector of the river. The DLQ, on the other hand, is noticeably affected by the superelevation, disappearing in the upper river even at stages of low river flow.

3. <u>Relation between Sacramento and Other River Stations</u>

Figure 25 shows the 28-day mean tide levels for all the river stations plotted against the mean river levels for the same 28-day interval at Sacramento. This figure can be used to estimate the 28-day observed MTL expected for any station downriver knowing the 28-day mean river level at Sacramento. Lines of regression were fitted to these relationships and the statistics from these are shown in Table 20. Reference can then be made to the individual station graphs in Appendix A to determine probable values for datums and ranges at that river level. Using standard tide tables of predicted tides for San Francisco, the linear relationships shown in Figure 25, and the real time mean river level at Sacramento, water levels and tide ranges can be then predicted for the stations in between.

4. <u>Accuracy of Datum Determination from Short Observations</u>

At secondary stations, a short series of tide observations is compared to a reference station for computation of 19-year datums. A one-year observation interval is a standard recording period used by NOS for secondary stations today. Mean datums and ranges were produced for Sacramento over the 18-month period of this study and are included in Table 3. Data limitations restricted the ability in this study to produce statistics on the reliability of a one-year length of comparison in the river system. It was also

considered that results obtained using one-year data samples could be accurately extrapolated from the products derived using shorter sample intervals and that they would not differ much from the 28 and 56-day results. The latter proved to be the case. Hydrographic survey limitations occasionally require comparisons to be made from shorter periods of observation, NOS Form 248 being used for comparisons of seven-day or fewer observations.

In this study it was decided to use a series of short-period observations for the purpose of evaluating the effects of the length of tide observations on the effective 19-year datums and ranges produced. Accordingly, four observation intervals were chosen of 7, 14, 28, and 56 days. Seven days approximates the shortest series of tide observations generally used historically in hydrographic surveying, as stated above, and 28 days approximates the commonly used one-month comparison interval. It may be noted that the interval of 14 days is the closest full-day approximation to the prominent fortnightly cycle of spring/neap tides, and so any averaging over this period or its multiples would be expected to minimize variations in the means obtained. The four observation intervals were also selected to form a geometric progression to simplify interpolation or extrapolation of results obtained to other tide observation periods than these.

In order to present a picture of how the water levels can vary over short observation periods and of the effects of averaging these variations, 7, 14, 28, and 56-day running means of the tide heights and their differences at Presidio were computed for the study period. Time series plots of these are shown in Figures 13 and 14 and 26-31. The variability of the prominent fortnightly tide cycle can be clearly seen in Figures 26-29 produced from the 7 and 14-day running means. Figures 30 and 31, produced from a 56-day running mean, effectively average out these fortnightly variations.

For contrast, the effects of 7, 14, 28, and 56-day tide observations at a river station are shown in Figures 11 and 12 and 32-37 for Sacramento. These figures show the fluctuations of the river to greatly exceed the tidal influence; nevertheless, the fortnightly spring/neap cycles appear prominently in the ranges computed from a seven-day comparison in Figure 33 during low river stages. Figure 36 shows the damping effect of a longer comparison interval on both the river and spring/neap fluctuations, and Figure 37 shows the corresponding ranges.

Evaluations of the effect of the length of tide observations over the study period on computed 19-year datums and ranges were performed using tide data from Sacramento. Scatter graphs, such as shown in Figure 38 of the 19-year datums and ranges plotted against the computed

mean river level for the same comparison interval, were prepared for each of the four comparison intervals and are included in Appendix A. A line of regression, which may be thought of as a line of datums or ranges, was computed for each of these scatter graphs and the statistics developed are given in Tables 16-19 and are graphically summarized in Figures 39-47. The figures and tables give the slope and y-axis intercept of the lines of regression and the standard deviation of the data points about this line, each plotted against the length of comparison.

The figures show that the slope values and y-intercept are very nearly independent of the tide observation period. The standard deviations, however, show a definite decrease with increased length of comparison for all 19-year datums and ranges. An eightfold increase in the length of comparison, from 7 to 56 days, reduces the standard deviation of the 19-year MTL about the short-term observed mean river level by a factor of two according to Figure 39. A similar reduction in the standard deviation about the lines of regression for the other datums and ranges can be seen in Figures 40-47. The scatter graphs show that most of the variability of these standard deviations occurs at lower river levels, the tides disappearing at high water levels.

Swanson [1974] used the standard procedure for comparison of simultaneous observations to compute the accuracy

of datum determination with comparison intervals ranging from one month to one year for oceanic stations in the same tide regime. His graphs also show dependency of the the accuracy on the length of comparison. The standard deviations shown in Figure 42 for MHW and in Figure 43 for MHHW are very nearly identical to the standard deviations for these high waters found by Swanson [1974, p. 11-12, Figures 8 and 10] over the common sampling interval (one to two months) for the standard method of comparison on the Pacific coast. The rate of accuracy change with sampling interval for the over-lapping data are in agreement; therefore, the rate of change determined by Swanson can be used to estimate the accuracy which would be expected at Sacramento from even longer comparison intervals than presented here. Swanson's data all pertain to oceanic tide stations where river effects on the water level are negligible. Thus, it is of particular interest here to note that the dependency of the accuracy of high water datum determination on the length of observation is independent of whether the secondary station is located in the oceanic or riverine environment.

Accuracy of computed 19-year low water datums show a similar rate of improvement with longer sampling intervals, but the accuracy of low water datum determination in this river system is about 40% lower than it is for high water datums. These determinations for low water datums show

standard deviations of up to 0.180 foot at Sacramento, which is 35% less accurate than the low water standard deviations found by Swanson for the West Coast. Surprisingly, it is about the same as the 0.183 foot standard deviation he found for the Gulf Coast using the standard procedure. The accuracy of determination of the mean tide level found here is close to that found by Swanson [1974, p. 12, Figure 10].

VII. CONCLUSIONS

The standard method of comparison of simultaneous observations can be applied in the Sacramento River system in order to produce internally consistent 19-year datums and ranges. The validity of using this procedure is based on the fact that linear relationships can be developed between the datums and ranges and the river levels. Considering the variability of river fluctuations, the reduction in precision of determination that occurs upriver appears acceptable. Two assumptions are made in the use of the procedure: (1) The difference between the mean tide level over the period of observation and the actual 19-year mean tide level is the same at both the standard and subordinate stations, and (2) the ratio of the observed ranges to the actual 19-year ranges is the same for both stations.

In regard to the first assumption, for a secondary station located where river discharge produces a water-level superelevation above the ocean level, a weakness of the standard comparison procedure applied in a river system is the method of determination of the 19-year MTL. The standard procedure applies the height difference between the observed MTL at the primary station and its 19-year MTL, termed a corrector, to the observed MTL at the secondary station. This difference may amount to a foot at Presidio for a

seven-day observation period and half a foot for a 28-day period. This difference cannot be expected to travel upriver as a constant quantity but should undergo a reduction and/or amplification proportional to that experienced by the ranges or inequalities. A question remains as how to best apply this difference upriver. It is possible that the difference diminishes rapidly upriver as does the diurnal low inequality. This can be determined with assurance only from a long series of observations at secondary stations. It should be pointed out that applying this corrector in a place where it is inappropriate induces oscillations in the 19-year MTL which are not real. A comparison of the MTL in Figure 26 with the MTL in Figure 32 shows that the fluctuations are the inverse of one another, indicating that this MTL corrector is inappropriately applied at Sacramento.

The second assumption appears valid for all probable mean river levels at all secondary stations, except Benicia, there being a well-defined linear correlation between river level and range reduction or amplification through the river system (Tables 11-15 and 18, Figures 21 and 22). An unusual situation occurs at Benicia where it was difficult to get a close linear fit between the ranges and the mean river level (Figures 21 and 22). The diurnal low inequality at low river levels was found often to behave as if the lowest waters could not overcome the seaward current through Carquinez Strait.

Tidal ranges diminish with increased superelevation of the water level in the Sacramento River, disappearing completely at certain high river stages except in San Pablo Bay where some range amplification is seen with the relatively small superelevation which occurs there. The diurnal low inequality is affected more by the river superelevation than is the diurnal high inequality.

The 19-year mean tide levels and high water tidal datums can be computed in the river system with an accuracy comparable to that resulting from comparisons in an oceanic environment found by Swanson [1974] for the same observation interval. Low water datum determination is less accurate than high water determination in the river system. Nineteen-year tidal datums determined from short comparisons are dependent, though, on the specific superelevation of the river.

A method has been developed here having a straightforward statistical basis, using tide observations collected over observation periods on the order of a year at secondary river stations, where a 19-year record is available for both an oceanic reference station (Presidio) and a river reference station (Sacramento), for obtaining the elevation of the standard tidal datums along the full extent of the river system in which tidal oscillations occur.

The method involves determination of precise values for 19-year datums and ranges anywhere up the river system in the following way for a chosen mean river level. For each datum and range at each river station, precise regression equations have been developed expressing the computed 19-year datums and ranges as a function of the river level; these are given in Tables 11-19. Substituting the chosen river level into these equations, one can then calculate consistent datums and ranges by simply multiplying the MTL by the slope and then adding the y-intercept. For example, the monthly mean river level at Sacramento for the epoch years 1960-1978 is 7.54 feet NGVD (Table 3). From the relationships presented in Table 18, 19-year datums and ranges can then be computed around this mean river level for Sacramento for the epoch 1960-1978 and are included in Table 3. It may be noted from the table that the standard deviation of the mean river level over this 19-year period of observations is almost five feet.

In the example just considered, the mean of 19 years of river level measurements was chosen for establishing tidal datums for the 1960-1978 epoch for Sacramento. However, there are other logical choices of mean river level that can be derived from these long-term measurements around which tidal datums may be desired. These long-term river level measurements may provide a statistical basis for the choosing of suitable river levels around which to determine tidal datums. A histogram for this purpose is included as Figure 48 which shows the

height distribution of monthly mean river levels at Sacramento for the eopch years 1960-1978.

For levee design or the determination of property boundaries, a statistically high river level may be chosen. For navigation purposes a low level datum would be chosen. With regard to the latter, it may be noted in Table 3 (upper part) that the tidal datums at Sacramento cluster about the long-term mean river level, but that because of the wide variations in river elevation, water levels below MLLW occur much of the time (lower part). Accordingly, a datum for navigation at Sacramento would best be chosen at a river level substantially below this MLLW. In oceanic tide regimes, where tides are the only influence on water level, fluctuations below the low water datum chosen for navigation are statistically infrequent and of small magnitude. In a river environment, a statistical low water level must be developed for both influences, river level and tidal fluctuations. The data in Figure 48 might be used to choose a suitable low river level. Some possible choices for a low water navigation reference at Sacramento are: (1) the ten-percent quantile water level (3.58 feet), which approximates the lowest waters in a normal summer season at Sacramento, (2) the minimum value found in a 19-year record (1.98 feet, for 1960-1978), which is a low water level in an unusuahly dry summer, and possibly (3) the hypothetical river level if the river stopped flowing

altogether, which would be calculated by the MTL y-intercepts as discussed previously (0.18 feet, Table 10). At any one of these river levels, a MLLW with respect to that level can be determined, and used as the nautical charting datum. With any one of these choices it would be possible to establish a datum which is continuous throughout the transition zone of the Sacramento River System. In practice, tidal zoning, defining separate datums for each section of the river, would be required.

With regard to the question raised in the introduction, results obtained here for the Sacramento River System show that there is no natural discontinuity or feature along the river system that can be objectively used to terminate up-river tide measurements for datum determination purposes. However, there are several possible criteria that might be adopted for this purpose, each requiring an arbitrary specification: (1) A specified ratio of mean river superelevation (MTL in Table 6) to the mean tide range (MN in Table 6), (2) a specified ratio of river variability (manifested by the MTL in Table 9) to tidal variability (GR in Table 6), (3) a specified percentage of time that a tidal influence prevails (for example, the point where the tide shows some influence half of the time is where the median river superelevation equals the level of no tide; this point is above nine feet upriver from Sacramento.

feet this point is upriver from Sacramento), and (4) the point above which the river has no tides. The position of the last choice cannot be determined from the data studied, but requires knowledge of the river gradient above Sacramento. Assuming the river gradient is similar above Sacramento to that below, the tides will travel an additional 100 NM beyond Sacramento at a low river level, based on the rate of range decrease along the confined section of the channel from Walnut Grove to Sacramento indicated in Figure 7 (Table 7).

The results of this study raise the following questions: (1) Can the procedure developed for the Sacramento River System be applied over the entire Sacramento-San Joaquin delta region, (2) over what extent of the Sacramento-San Joaquin delta region can the Sacramento 19-year reference station be used to determine water levels at other stations, and (3) is a separate reference station needed on the upper San Joaquin river system? The California/NOS cooperative tides program of 1977-1979 involved the synoptic collection of tide data from some 53 stations throughout the delta region above Carquinez Strait, and the California Division of Water Resources maintains some 43 longer term recording stations in the region. This wealth of data may provide the means for answering these questions.

Table 1. TIDE STATION LOCATIONS

SYMBOL	STATION NAME	HYDROMORPHIC LOCATION	NAUTICAL MILES
P	PRESIDIO	GOLDEN GATE	0
O	POINT ORIENT	SAN PABLO BAY	10
H	HERCULES	SAN PABLO BAY	17
B	BENICIA	CARQUINEZ STRAIT	31
M	MALLARD ISLAND	EASTERN SUISUN BAY	44
C	COLLINSVILLE	*EASTERN SUISUN BAY	48
T	THREE MILE SLOUGH	WIDE RIVER CHANNEL	56
W	WALNUT GROVE	CONFINED RIVER CHANNEL	83
S	SACRAMENTO	CONFINED RIVER CHANNEL	111

*River juncture, Sacramento-San Joaquin

Table 2. TIDE DATA

STATION NAME	SOURCE & STATION NUMBER	DATA FORMAT	LEVEL OF NGVD ON STAFF[2]	OBSERVATION PERIOD	NUMBER OF GAPS EDITABLE	NUMBER OF GAPS UNEDITABLE
PRESIDIO	NOS	Analog Record	8.61	1/1/78-2/30/78	2	0
PRESIDIO	NOS 4290	Mag. Tape[1]	8.61	3/1/78-8/1/79	8	0
POINT ORIENT	NOS 4881	Mag. Tape	9.92	1/2/78-5/7/79	2	0
BENICIA	NOS 5111	Mag. Tape	30.70	2/2/78-7/1/79	2	0
MALLARD ISLAND	NOS 5112	Mag. Tape	11.74	3/2/78-10/22/78	2	1
COLLINSVILLE	NOS 5176	Mag. Tape	8.12	1/6/78-10/1/78	1	1
THREE MILE SLOUGH	NOS 5236	Mag. Tape	8.15	1/9/78-6/30/79	2	5
WALNUT GROVE	NOS 5489	Mag. Tape	6.72	1/1/78-6/30/79	1	3
SACRAMENTO	USGS 11-4475	Tabulation 15-Minute	0.0	1/1/78-7/1/79	2	1

[1]Magnetic tape records are six-minute data from digital punch-tape gauges.

[2]Provided by NOS and USGS (written correspondence); the value for Walnut Grove is preliminary.

Table 3. TIDE DATA FOR SACRAMENTO

All elevations and ranges are in feet.

19-YEAR DATUM	MEAN VALUES* FOR EPOCH 1960-1978	MEAN VALUES FOR STUDY PERIOD 1/78-6/79
MHHW	7.99 NGVD	7.40 NGVD
MHW	7.77	7.17
MRL	7.54	6.85
MLW	7.17	6.53
MLLW	7.07	6.42
19-YEAR RANGE		
GR	0.920	0.947
MN	0.602	0.642
DHQ	0.216	0.224
DLQ	0.100	0.108
STATISTICS FROM MONTHLY MEAN WATER LEVELS	FOR EPOCH 1960-1978	STUDY PERIOD 1/78-6/79
MEAN	7.54 NGVD	7.07 NGVD
MEDIAN	5.69	5.27
MAXIMUM	22.55	17.59
MINIMUM	1.98	3.67
10% QUANTILE	3.58	3.75
STD. DEVIATION	4.73	4.20

*Computed from the mean river level of 7.54 (from lower part of table) and the relationships found in Table 18.

Table 4. TIDAL DATUMS AND RANGES

Daily Tides:	HHW	- Higher High Water
	LHW	- Lower High Water
	HLW	- Higher Low Water
	LLW	- Lower Low Water
Tidal Datums:	MHHW	- Mean Higher High Water
	MHW	- Mean High Water = 1/2 (MHHW + MLHW)
	MLHW	- Mean Lower High Water
	MTL	- Mean Tide Level = 1/2 (MHW + MLW)
	MHLW	- Mean Higher Low Water
	MLW	- Mean Low Water = 1/2 (MHLW + MLLW)
	MLLW	- Mean Lower Low Water
Tidal Ranges:	DHQ	- Diurnal High Inequality = MHHW - MHW
	DLQ	- Diurnal Low Inequality = MLW - MLLW
	MN	- Mean Range = MHW - MLW
	GR	- Diurnal or Greater Range = MN + DHQ + DLQ or = MHHW - MLLW

Table 5. TIDE DATA FOR PRESIDIO

All elevations and ranges are in feet.

DATUM	EPOCH 1941-1959 STAFF	EPOCH 1941-1959 NGVD	EPOCH 1960-1978 STAFF	EPOCH 1960-1978 NGVD	STUDY PERIOD 1/78 - 7/79 NGVD
MHHW	11.46	2.85	11.60	2.99	3.00
MHW	10.86	2.25	11.00	2.39	2.44
MTL	8.86	0.25	8.95	0.34	0.42
MSL	8.80	0.19	8.90	0.29	0.31
NGVD*	8.61	0.00	8.61	0.00	0.00
MLW	6.87	-1.74	6.90	-1.71	-1.61
MLLW	5.75	-2.86	5.77	-2.84	-2.56

*Geodetic datum

RANGE	EPOCH 1941-1959	EPOCH 1960-1978	STUDY PERIOD
MN	3.99	4.10	4.05
GR	5.71	5.83	5.56
DHQ	0.60	0.60	0.56
DLQ	1.12	1.13	0.95

TABLE 6: MEAN TIDAL DATUMS AND RANGES IN THE SACRAMENTO RIVER

derived from 28-day observation intervals

	STATION						
19-YEAR DATUM	P	C	B	M	T	W	S
MHHW	2.990	3.245	3.144	3.152	3.446	3.368	7.396
MHW	2.390	2.658	2.645	2.677	2.992	3.481	7.172
MTL	0.340	0.465	0.674	1.073	1.348	2.441	6.851
MLW	-1.710	-1.727	-1.298	-0.531	-0.297	1.401	6.530
MLLW	-2.840	-3.247	-2.532	-1.455	-1.181	0.988	6.422
19-YEAR RANGE							
GR	5.830	6.492	5.677	4.606	4.626	2.380	0.974
MN	4.100	4.385	3.943	3.207	3.289	2.080	0.642
DHQ	0.600	0.587	0.499	0.475	0.453	0.387	0.224
DLQ	1.130	1.520	1.234	0.924	0.884	0.413	0.108

TABLE 7: LOW WATER TIDAL DATUMS AND RANGES IN THE SACRAMENTO RIVER
derived from 28-day observation intervals

19-YEAR DATUM	STATION P	C	B	M	T	W	S
MHHW	2.990	3.040	2.840	2.910	3.010	3.110	4.140
MHW	2.390	2.450	2.350	2.420	2.560	2.730	3.850
MTL	0.340	0.310	0.460	0.870	0.940	1.640	3.350
MLW	-1.710	-1.920	-1.500	-0.690	-0.690	0.540	2.840
MLLW	-2.840	-3.490	-2.870	-1.640	-1.490	0.090	2.660
19-YEAR RANGE							
GR	5.830	6.900	6.110	4.900	4.950	3.240	1.550
MN	4.100	4.660	4.260	3.400	3.540	2.370	1.030
DHQ	0.600	0.620	0.560	0.520	0.500	0.470	0.480
DLQ	1.130	1.660	1.420	1.060	1.030	0.530	0.360

TABLE 8: HIGH WATER TIDAL DATUMS AND RANGES IN THE SACRAMENTO RIVER

derived from 28-day observation intervals

	STATION						
19-YEAR DATUM	P	O	B	M	I	W	S
MHHW	2.990	3.520	3.440	3.390	3.780	6.270	17.270
MHW	2.390	2.930	2.550	2.940	3.340	6.260	17.270
MTL	0.340	0.630	0.510	1.320	1.700	5.610	17.170
MLW	-1.710	-1.610	-1.100	-0.280	0.110	4.950	17.140
MLLW	-2.840	-3.140	-2.280	-1.080	-0.780	4.890	17.060
19-YEAR RANGE							
GR	5.830	6.360	5.280	4.300	4.410	1.380	0.150
MN	4.100	4.290	3.720	3.070	3.170	1.310	0.0
DHQ	0.600	0.540	0.430	0.400	0.380	0.0	0.0
DLQ	1.130	1.460	1.060	0.740	0.760	0.060	0.0

TABLE 9: DIFFERENCES BETWEEN MAXIMUM AND MINIMUM DATUMS AND RANGES derived from 28-day observation intervals

19-YEAR DATUM	STATION P	C	B	M	I	W	S
MHHW	0.0	0.480	0.600	0.480	0.770	3.160	13.130
MHW	0.0	0.480	0.600	0.520	0.780	3.530	13.420
MTL	0.0	0.320	0.450	0.450	0.760	3.970	13.820
MLW	0.0	0.310	0.400	0.410	0.800	4.410	14.300
MLLW	0.0	0.350	0.590	0.560	0.710	4.800	14.400
19-YEAR RANGE							
GR	0.0	0.540	0.830	0.600	0.540	1.860	1.400
MN	0.0	0.370	0.540	0.330	0.370	1.060	1.030
DHQ	0.0	0.080	0.130	0.120	0.120	0.470	0.480
DLQ	0.0	0.200	0.360	0.320	0.270	0.470	0.360

TABLE 10: TIDAL DATUMS AND RANGES WITHOUT RIVER SUPERELEVATION (y-intercepts)

derived from 28-day observation intervals

19-YEAR DATUM	P	C	B	M	T	W	S
	STATION						
MHHW	2.990	3.094	2.899	2.767	2.742	2.098	1.037
MHW	2.390	2.498	2.357	2.221	2.259	1.559	0.700
MTL	0.340	0.366	0.496	0.718	0.589	0.131	0.176
MLW	-1.710	-1.768	-1.365	-0.783	-1.034	-1.148	-0.348
MLLW	-2.840	-3.226	-2.440	-1.568	-1.787	-1.751	-0.516
19-YEAR RANGE							
GR	5.830	6.320	5.339	4.335	4.527	3.848	1.553
MN	4.100	4.265	3.722	3.005	3.292	2.707	1.047
DHQ	0.600	0.597	0.543	0.546	0.484	0.540	0.337
DLQ	1.130	1.459	1.075	0.785	0.752	0.602	0.168

TABLE 11: STATISTICS FOR POINT ORIENT

derived from 28-day observation intervals

19-YEAR DATUM	MEAN	MAXIMUM	MINIMUM	REGRESSION PARAMETERS SLOPE	REGRESSION PARAMETERS Y-INTERCEPT	STD DEVIATION
MHHW	3.245	3.520	3.040	0.266	3.094	0.077
MHW	2.656	2.930	2.450	0.282	2.498	0.076
MTL	0.465	0.630	0.310	0.176	0.366	0.052
MLW	-1.727	-1.610	-1.920	0.072	-1.768	0.051
MLLW	-3.247	-3.140	-3.490	-0.036	-3.226	0.069
19-YEAR RANGE						
GR	6.492	6.900	6.360	0.303	6.320	0.103
MN	4.385	4.660	4.290	0.211	4.265	0.069
DHQ	0.587	0.620	0.540	-0.016	0.597	0.016
DLQ	1.520	1.660	1.460	0.107	1.459	0.040

TABLE 12: STATISTICS FOR BENICIA

derived from 28-day observation intervals

19-YEAR DATUM	MEAN	MAXIMUM	MINIMUM	REGRESSION PARAMETERS SLOPE	Y-INTERCEPT	STD DEVIATION
MHHW	3.144	3.440	2.840	0.329	2.899	0.116
MHW	2.645	2.950	2.350	0.386	2.357	0.120
MTL	0.674	0.910	0.460	0.238	0.496	0.070
MLW	-1.298	-1.100	-1.500	0.090	-1.365	0.078
MLLW	-2.532	-2.280	-2.870	-0.123	-2.440	0.148
19-YEAR RANGE						
GR	5.677	6.110	5.280	0.452	5.339	0.227
MN	3.943	4.260	3.720	0.296	3.722	0.142
DHQ	0.499	0.560	0.430	-0.058	0.543	0.018
DLQ	1.234	1.420	1.060	0.213	1.075	0.097

TABLE 15: STATISTICS FOR MALLARD ISLAND

derived from 28-day observation intervals

19-YEAR DATUM	MEAN	MAXIMUM	MINIMUM	REGRESSION PARAMETERS SLOPE	REGRESSION PARAMETERS Y-INTERCEPT	STD DEVIATION
MHHW	3.152	3.390	2.910	0.322	2.767	0.091
MHW	2.677	2.940	2.420	0.381	2.221	0.097
MTL	1.073	1.320	0.870	0.297	0.718	0.068
MLW	-0.531	-0.280	-0.690	0.210	-0.783	0.051
MLLW	-1.455	-1.080	-1.640	0.095	-1.568	0.097
19-YEAR RANGE						
GR	4.606	4.900	4.300	0.226	4.335	0.150
MN	3.267	3.400	3.070	0.169	3.005	0.073
DHQ	0.475	0.520	0.400	-0.059	0.546	0.017
DLQ	0.924	1.060	0.740	0.116	0.785	0.092

TABLE 14: STATISTICS FOR THREE MILE SLOUGH

derived from 28-day observation intervals

19-YEAR DATUM	MEAN	MAXIMUM	MINIMUM	REGRESSION PARAMETERS SLOPE	REGRESSION PARAMETERS Y-INTERCEPT	STD DEVIATION
MHHW	3.446	3.780	3.010	0.491	2.742	0.145
MHW	2.992	3.340	2.560	0.512	2.259	0.138
MTL	1.348	1.700	0.940	0.514	0.612	0.115
MLW	-0.297	0.110	-0.690	0.514	-1.034	0.104
MLLW	-1.181	-0.780	-1.490	0.422	-1.787	0.098
19-YEAR RANGE						
GR	4.626	4.950	4.410	0.069	4.527	0.144
MN	3.289	3.540	3.170	-0.002	3.292	0.082
DHQ	0.453	0.500	0.380	-0.021	0.484	0.016
DLQ	0.884	1.030	0.760	0.092	0.752	0.069

TABLE 15: STATISTICS FOR WALNUT GROVE

derived from 28-day observation intervals

19-YEAR DATUM	MEAN	MAXIMUM	MINIMUM	REGRESSION PARAMETERS SLOPE	REGRESSION PARAMETERS Y-INTERCEPT	REGRESSION PARAMETERS STD DEVIATION
MHHW	3.868	6.270	3.110	0.724	2.098	0.135
MHW	3.481	6.260	2.730	0.786	1.559	0.129
MTL	2.441	5.610	1.640	0.914	0.205	0.125
MLW	1.401	4.950	0.540	1.042	-1.148	0.134
MLLW	0.988	4.890	0.090	1.120	-1.751	0.116
19-YEAR RANGE						
GR	2.880	3.240	1.380	-0.396	3.848	0.107
MN	2.080	2.370	1.310	-0.256	2.707	0.079
DHQ	0.387	0.470	0.0	-0.063	0.540	0.049
DLQ	0.413	0.530	0.060	-0.077	0.602	0.055

TABLE 16: STATISTICS FOR SACRAMENTO FROM A 7-DAY COMPARISON

19-YEAR DATUM	MEAN	MAXIMUM	MINIMUM	REGRESSION PARAMETERS SLOPE	Y-INTERCEPT	STD DEVIATION
MHHW	7.411	22.310	3.970	0.932	0.986	0.259
MHW	7.165	22.270	3.710	0.940	0.685	0.206
MTL	6.844	22.240	3.190	0.970	0.155	0.212
MLW	6.522	22.240	2.570	1.001	-0.377	0.259
MLLW	6.372	22.220	2.140	1.000	-0.524	0.282
19-YEAR RANGE						
GR	1.039	2.960	0.0	-0.068	1.510	0.316
MN	0.643	1.430	0.0	-0.061	1.063	0.199
DHQ	0.247	1.260	0.0	-0.008	0.301	0.163
DLQ	0.150	1.040	0.0	0.0	0.147	0.155

TABLE 17: STATISTICS FOR SACRAMENTO FROM A 14-DAY COMPARISON

19-YEAR DATUM	MEAN	MAXIMUM	MINIMUM	REGRESSION PARAMETERS SLOPE	Y-INTERCEPT	STD DEVIATION
MHHW	7.465	21.410	4.110	0.927	1.005	0.211
MHW	7.233	21.400	3.810	0.939	0.689	0.177
MTL	6.917	21.400	3.320	0.969	0.165	0.176
MLW	6.600	21.400	2.780	0.998	-0.359	0.215
MLLW	6.475	21.380	2.520	1.002	-0.507	0.214
19-YEAR RANGE						
GR	0.990	1.660	0.010	-0.075	1.512	0.232
MN	0.633	1.100	0.0	-0.060	1.048	0.175
DHQ	0.232	0.820	0.0	-0.012	0.316	0.104
DLQ	0.125	0.710	0.0	-0.003	0.148	0.094

TABLE 18: STATISTICS FOR SACRAMENTO FROM A 28-DAY COMPARISON

19-YEAR DATUM	MEAN	MAXIMUM	MINIMUM	REGRESSION PARAMETERS SLOPE	REGRESSION PARAMETERS Y-INTERCEPT	STD DEVIATION
MHHW	7.396	17.270	4.140	0.922	1.037	0.134
MHW	7.172	17.270	3.850	0.938	0.700	0.128
MTL	6.851	17.170	3.350	0.967	0.176	0.137
MLW	6.530	17.140	2.840	0.997	-0.348	0.180
MLLW	6.422	17.060	2.660	1.006	-0.516	0.169
19-YEAR RANGE						
GR	0.974	1.550	0.150	-0.084	1.553	0.176
MN	0.642	1.030	0.0	-0.059	1.047	0.154
DHQ	0.224	0.480	0.0	-0.016	0.337	0.070
DLQ	0.108	0.360	0.0	-0.009	0.168	0.063

TABLE 19: STATISTICS FOR SACRAMENTO FROM A 56-DAY COMPARISON

19-YEAR DATUM	MEAN	MAXIMUM	MINIMUM	REGRESSION PARAMETERS SLOPE	Y-INTERCEPT	STD DEVIATION
MHHW	7.254	15.600	4.380	0.917	1.054	0.100
MHW	7.036	15.600	4.100	0.938	0.695	0.096
MTL	6.717	15.470	3.640	0.970	0.155	0.109
MLW	6.399	15.340	3.170	1.003	-0.385	0.142
MLLW	6.303	15.340	3.000	1.014	-0.553	0.134
19-YEAR RANGE						
GR	0.951	1.450	0.180	-0.097	1.607	0.118
MN	0.637	0.970	0.020	-0.066	1.080	0.104
DHQ	0.218	0.430	0.0	-0.021	0.359	0.049
DLQ	0.096	0.250	0.0	-0.011	0.168	0.049

Table 20. REGRESSION STATISTICS FOR 28-DAY MEAN RIVER LEVELS AT RIVER STATIONS RELATIVE TO 28-DAY MEAN RIVER LEVELS AT SACRAMENTO.

STATION	Y-INTERCEPT	SLOPE	STANDARD DEVIATION
POINT ORIENT	0.114 NGVD	0.053	0.142 FEET
BENICIA	0.215	0.066	0.162
MALLARD ISLAND	0.095	0.109	0.213
THREE MILE SLOUGH	0.044	0.164	0.145
WALNUT GROVE	0.023	0.408	0.110

EXAMPLE: MRL(Walnut Grove) = 0.408 x MRL(Sacramento) + 0.023

(see Figure 25)

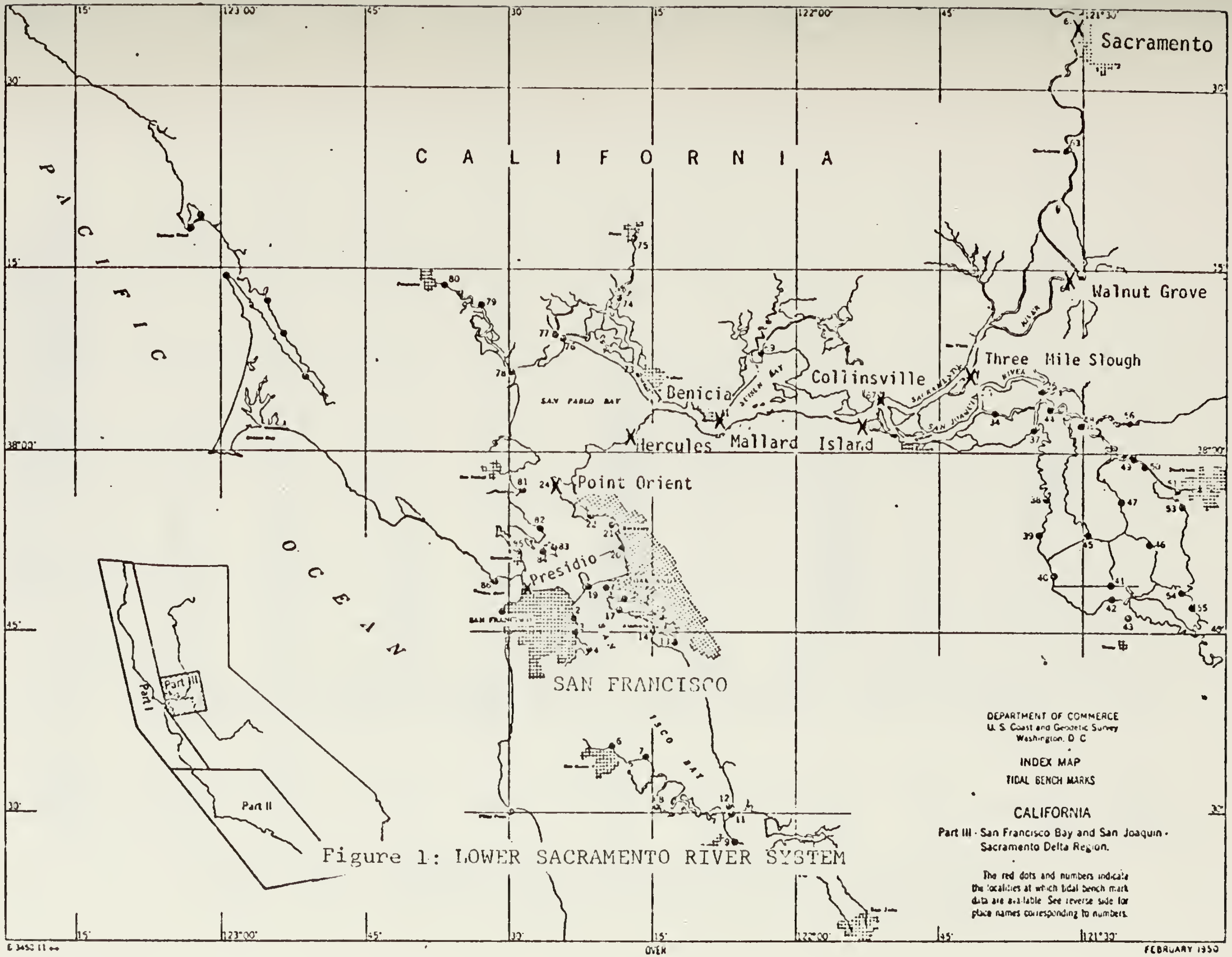


Figure 1: LOWER SACRAMENTO RIVER SYSTEM

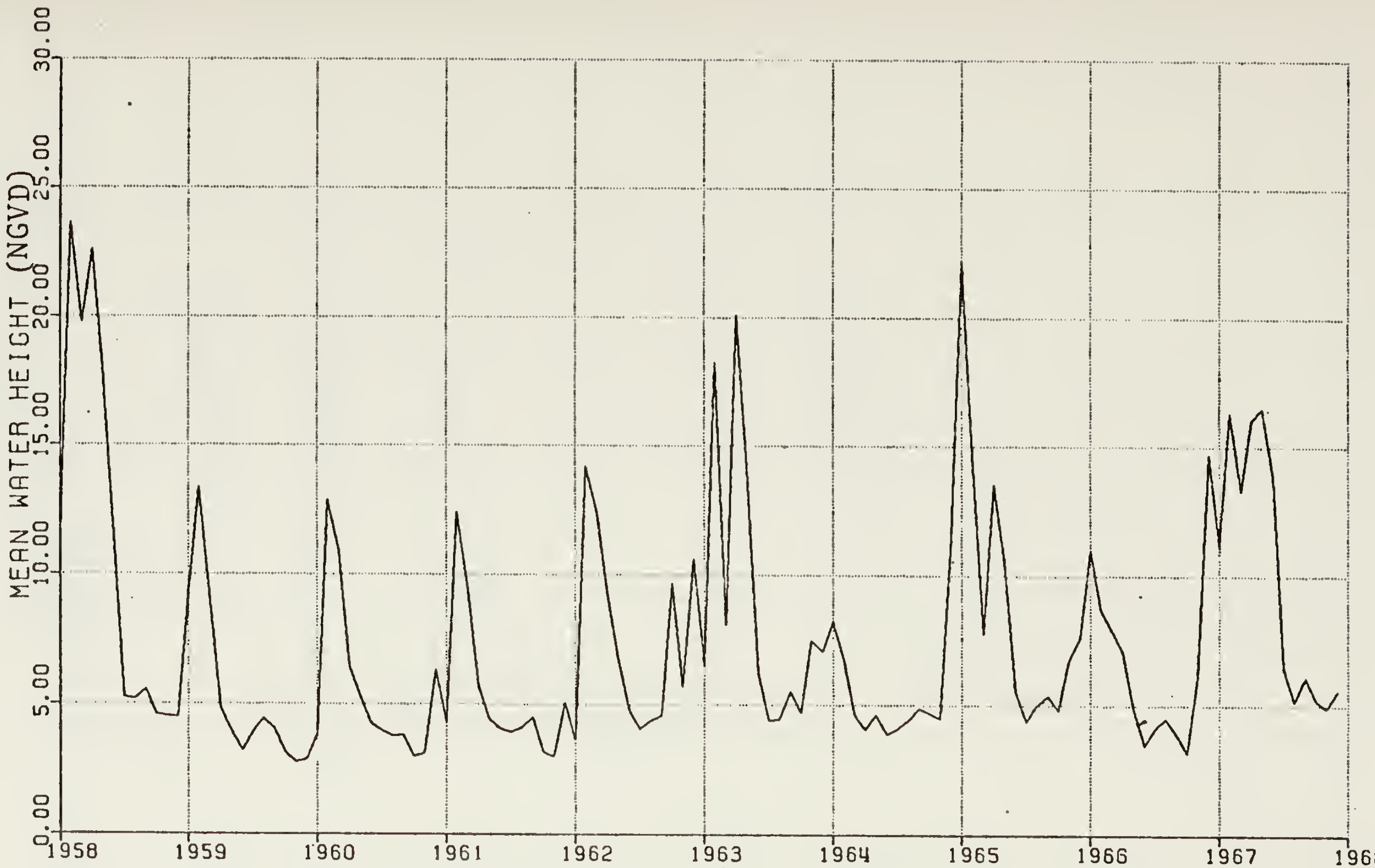


Figure 2A. MONTHLY MEAN RIVER LEVEL AT SACRAMENTO

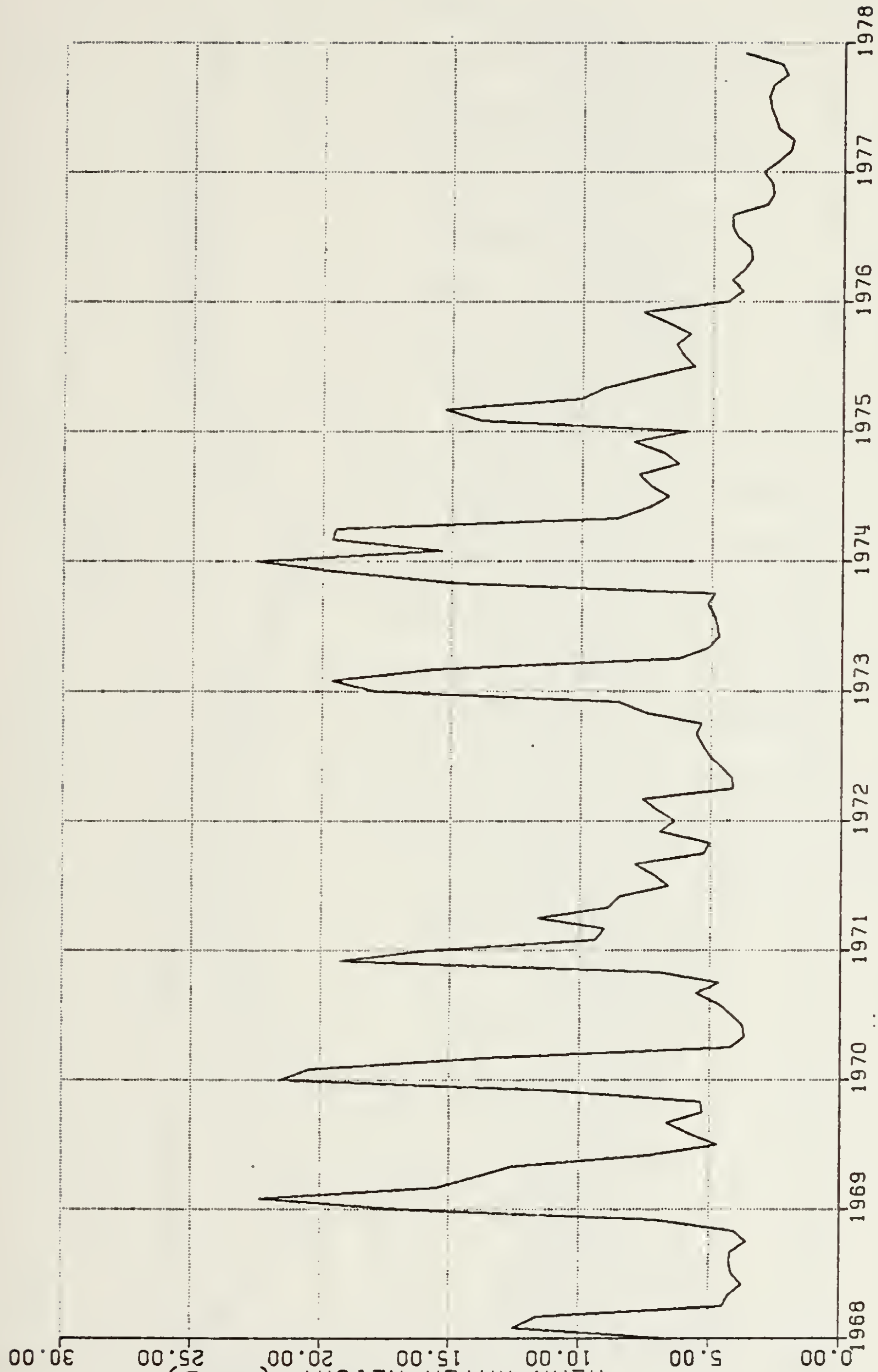


Figure 2B. MONTHLY MEAN RIVER LEVEL AT SACRAMENTO

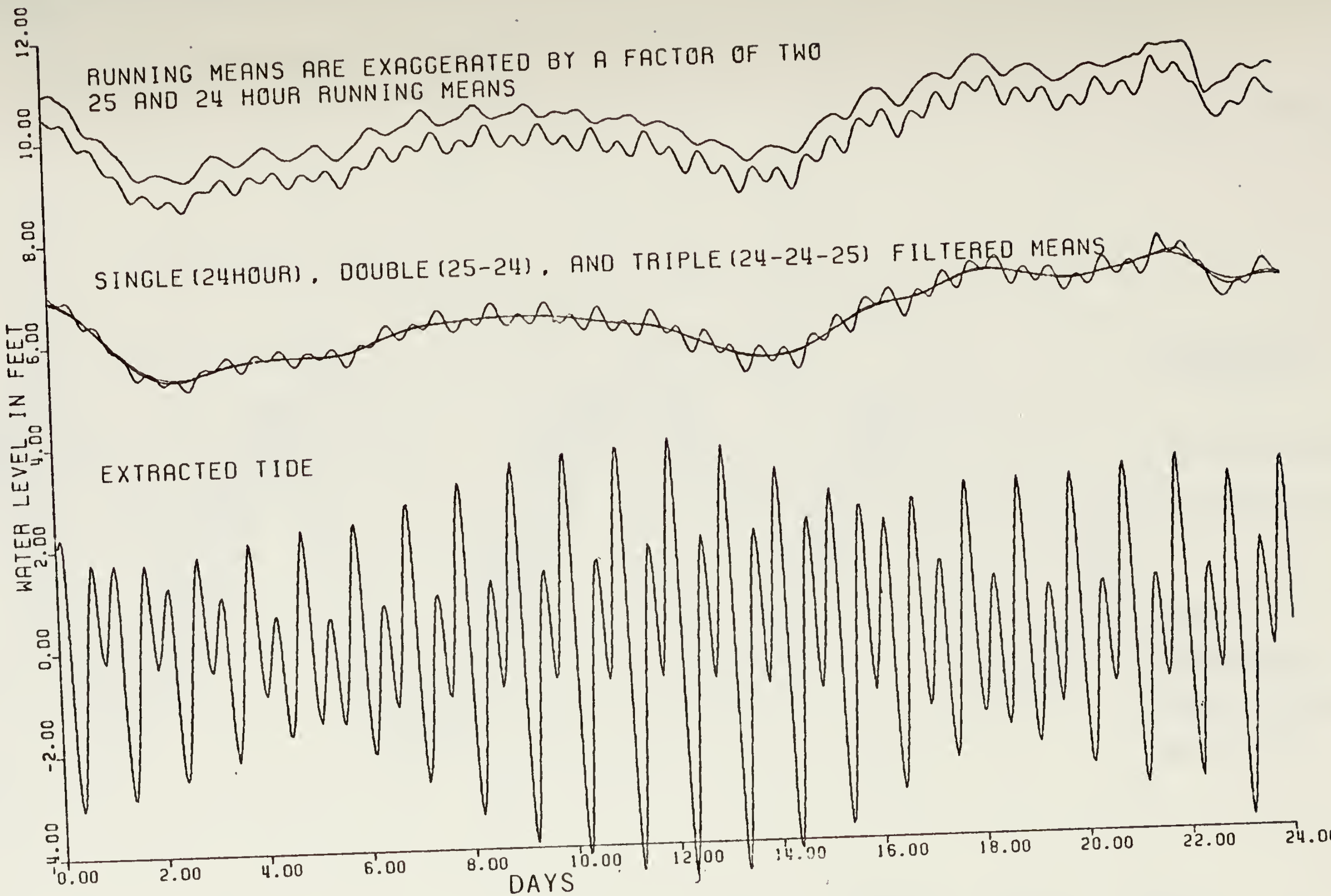


Figure 3. FILTERED RUNNING MEANS AND EXTRACTED TIDE AT PRESIDIO

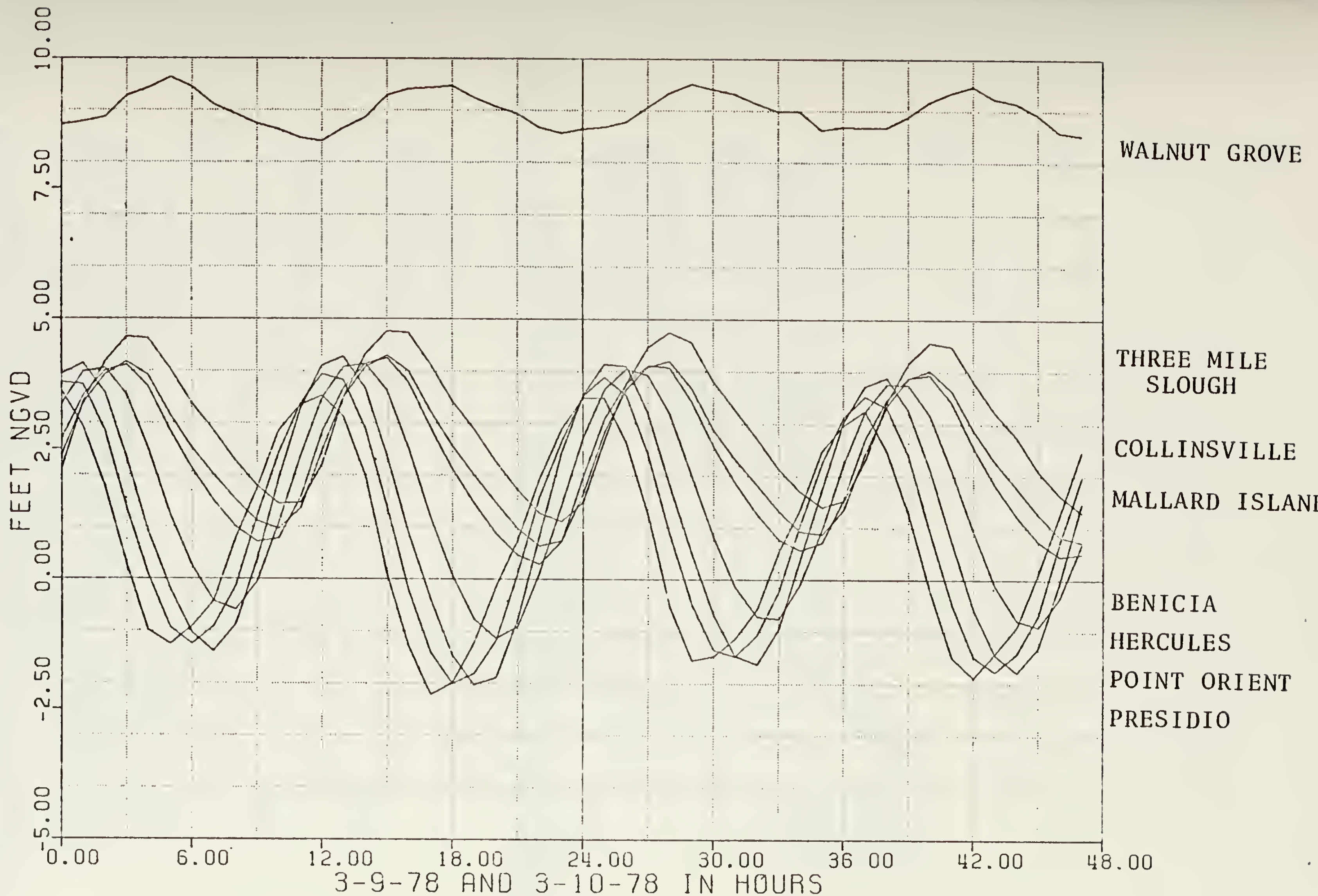


Figure 4. SIMULTANEOUS WATER LEVELS AT HIGH WATER IN THE SACRAMENTO RIVER

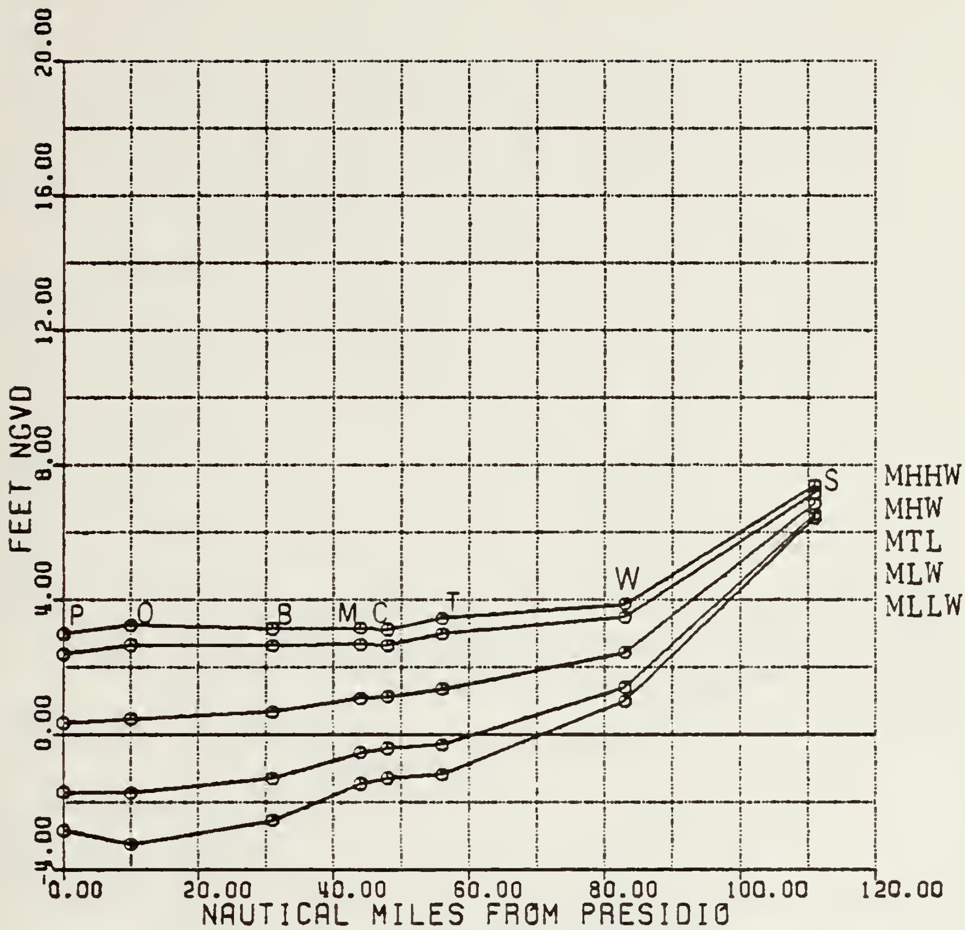


Figure 5. MEAN 19-YEAR TIDAL DATUMS ALONG THE SACRAMENTO RIVER SYSTEM FROM 28-DAY COMPARISONS OVER THE STUDY PERIOD.

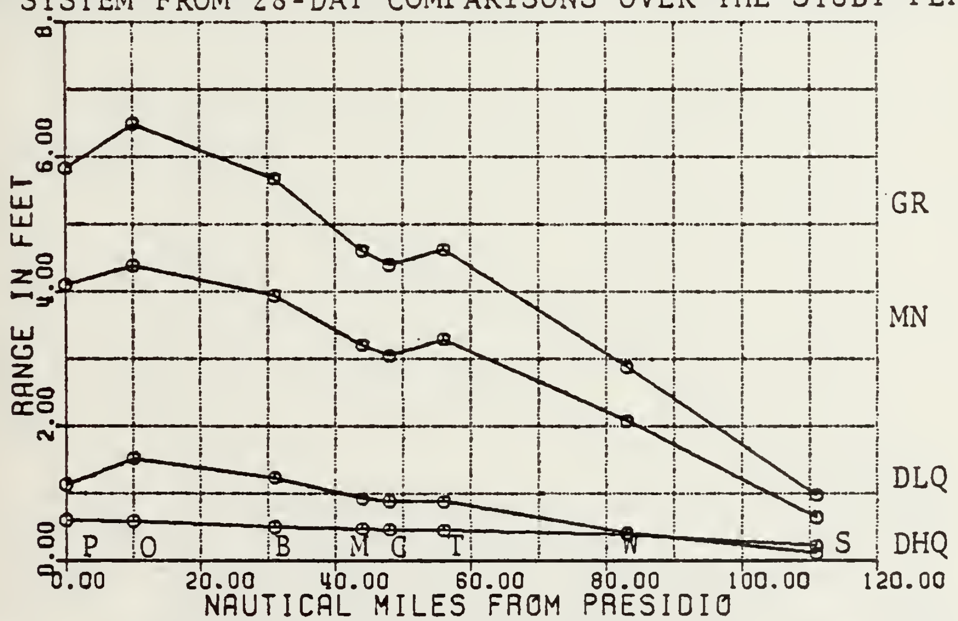


Figure 6. MEAN 19-YEAR TIDAL RANGES ALONG THE SACRAMENTO RIVER SYSTEM FROM 28-DAY COMPARISONS OVER THE STUDY PERIOD.

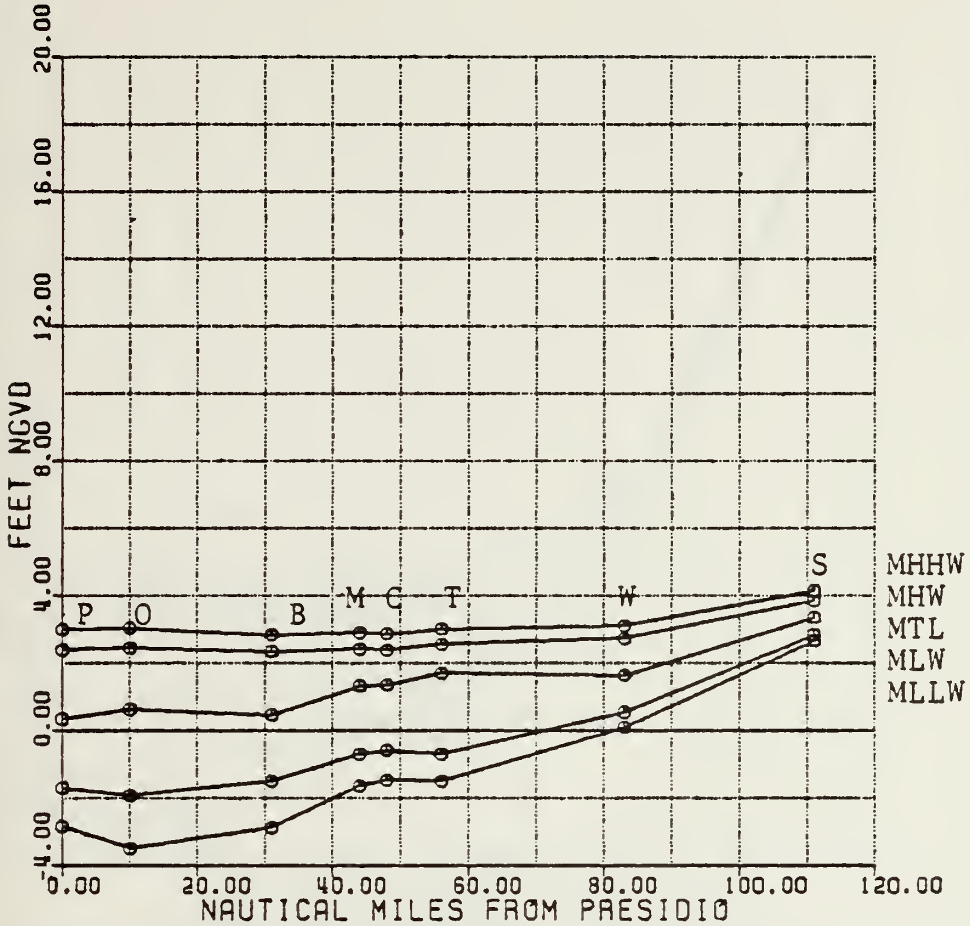


Figure 7. 19-YEAR TIDAL DATUMS AT LOW WATER ALONG THE SACRAMENTO RIVER SYSTEM FROM 28-DAY COMPARISONS

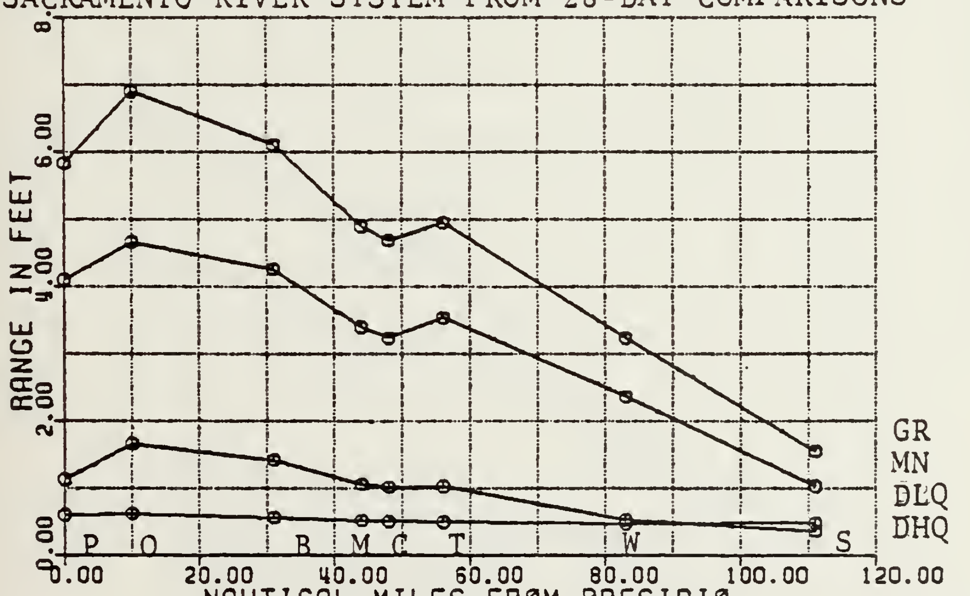


Figure 8. 19-YEAR TIDAL RANGES AT LOW WATER ALONG THE SACRAMENTO RIVER SYSTEM FROM 28-DAY COMPARISONS

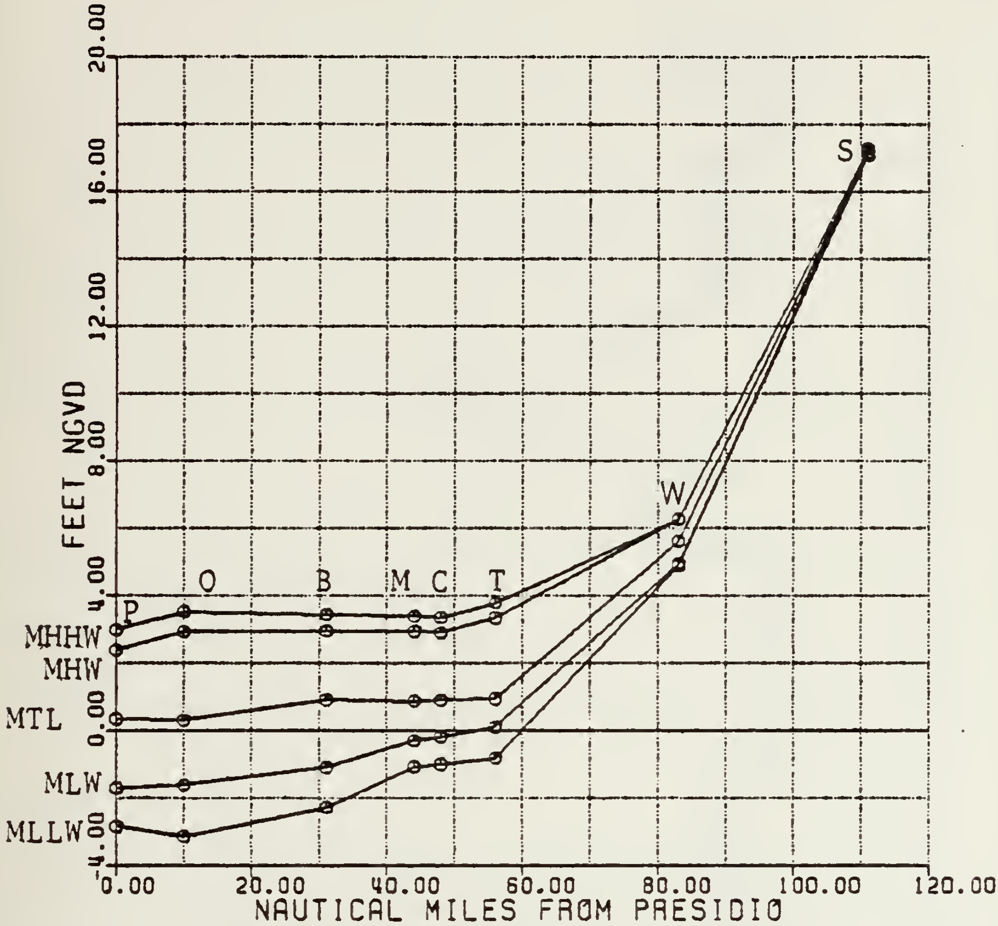


Figure 9. 19-YEAR TIDAL DATUMS AT HIGH WATER ALONG THE SACRAMENTO RIVER SYSTEM FROM 28-DAY COMPARISONS

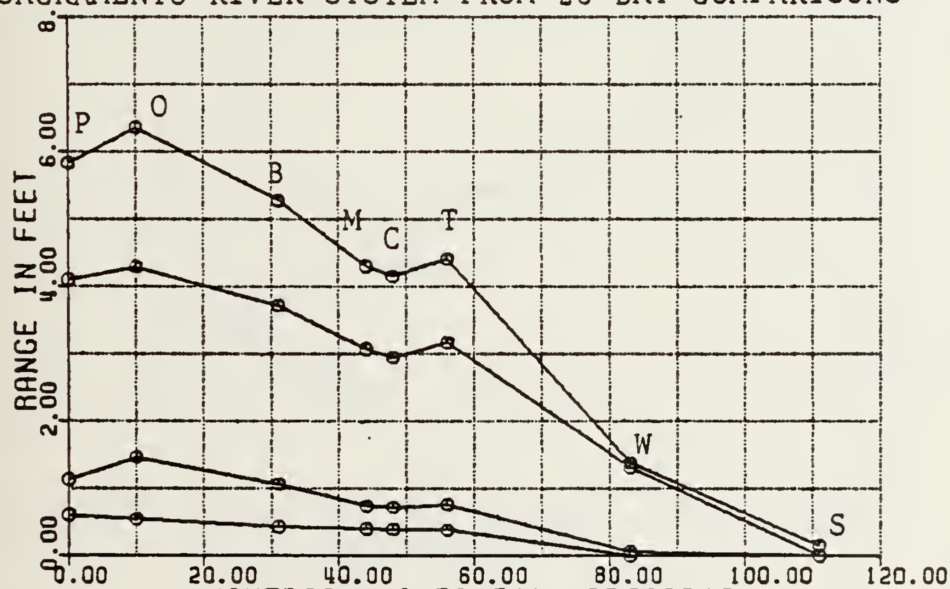


Figure 10. 19-YEAR TIDAL RANGES AT HIGH WATER ALONG THE SACRAMENTO RIVER SYSTEM FROM 28-DAY COMPARISONS

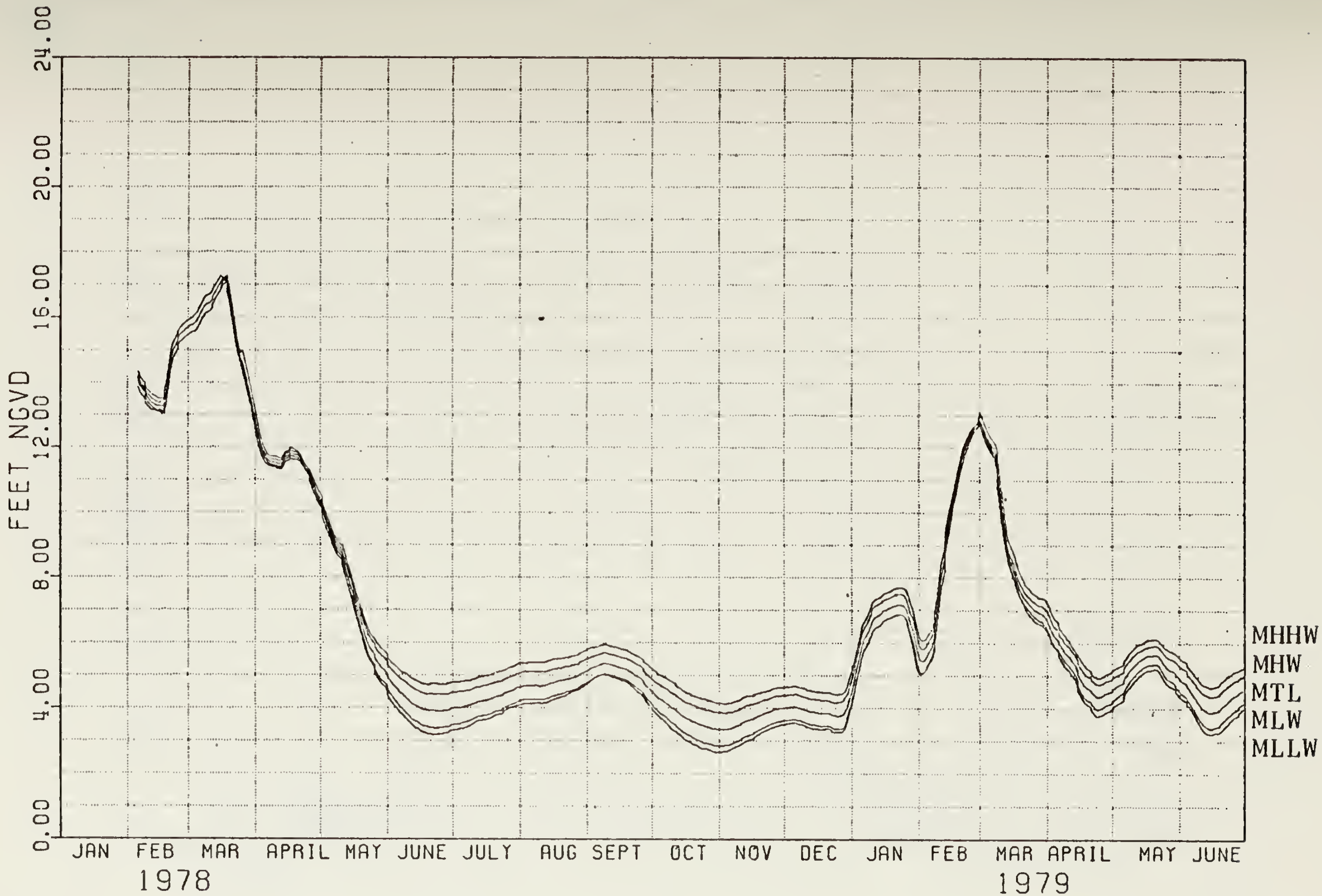


Figure 11. 19-YEAR TIDAL DATUMS AT SACRAMENTO COMPUTED WITH 28-DAY COMPARISONS

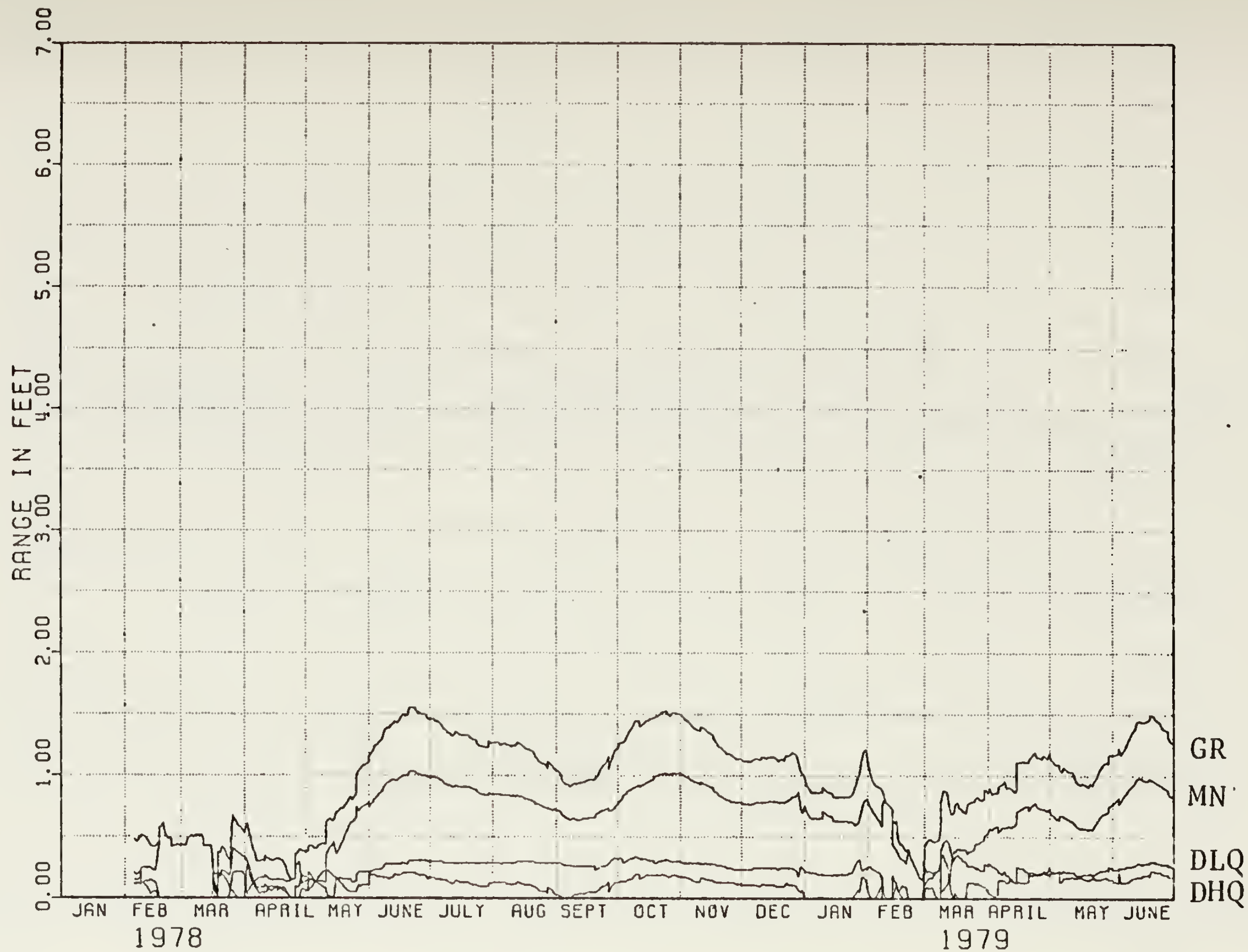


Figure 12. 19-YEAR TIDAL RANGES AT SACRAMENTO COMPUTED FROM 28-DAY COMPARISONS

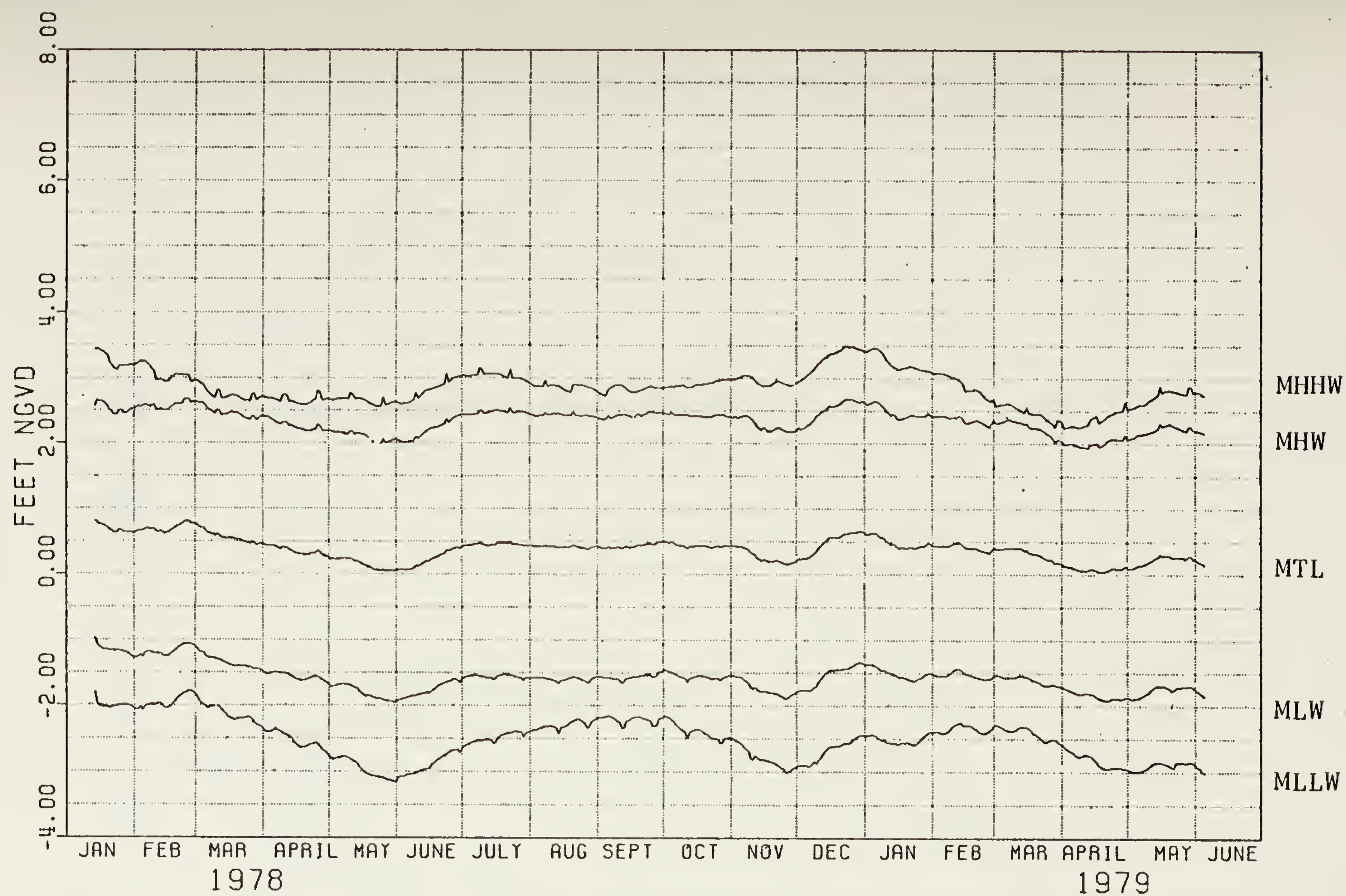


Figure 13. TIDAL DATUMS AT PRESIDIO FOR THE STUDY PERIOD COMPUTED WITH A 28-DAY RUNNING MEAN

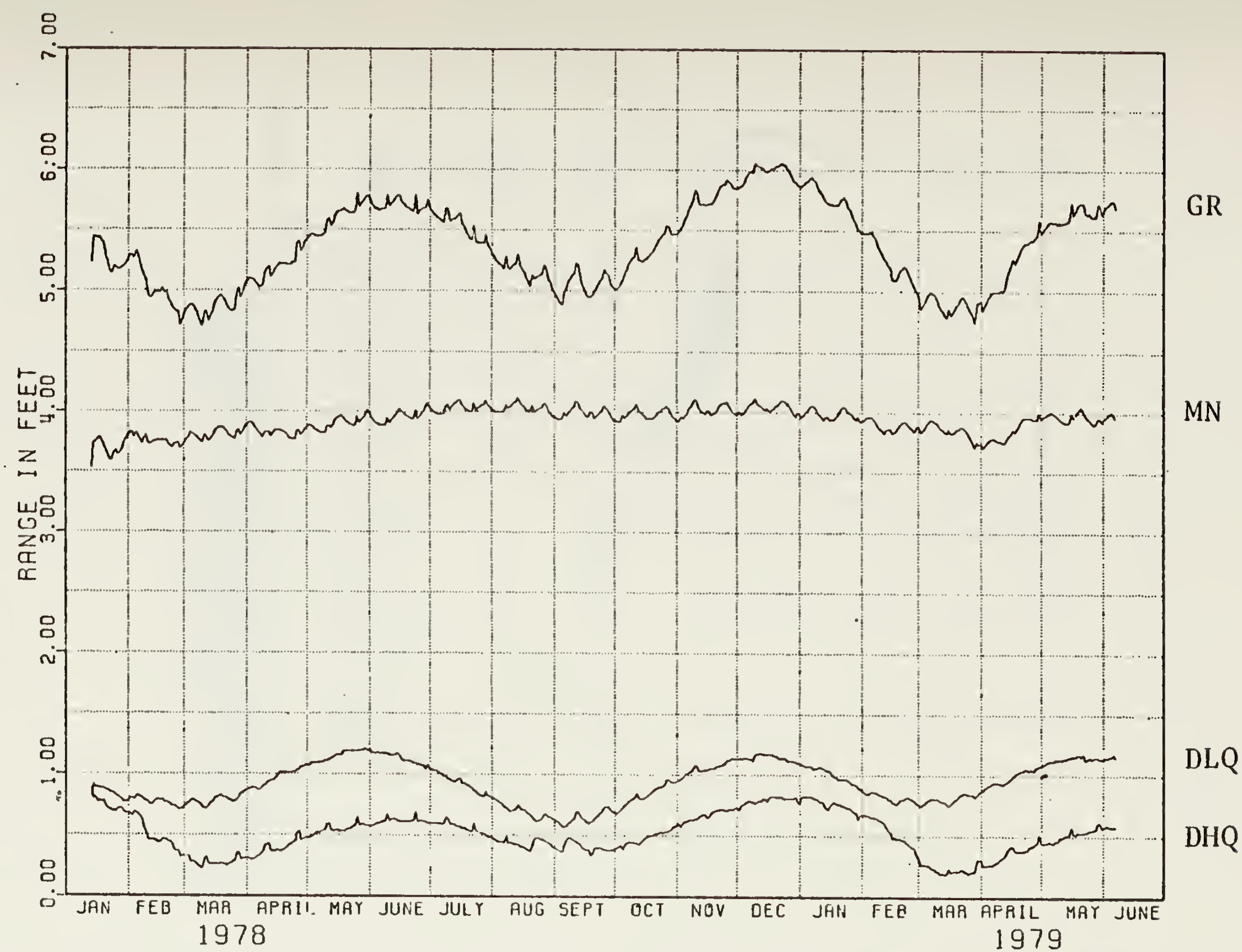


Figure 14. TIDAL RANGES AT PRESIDIO COMPUTED WITH A 28-DAY RUNNING MEAN

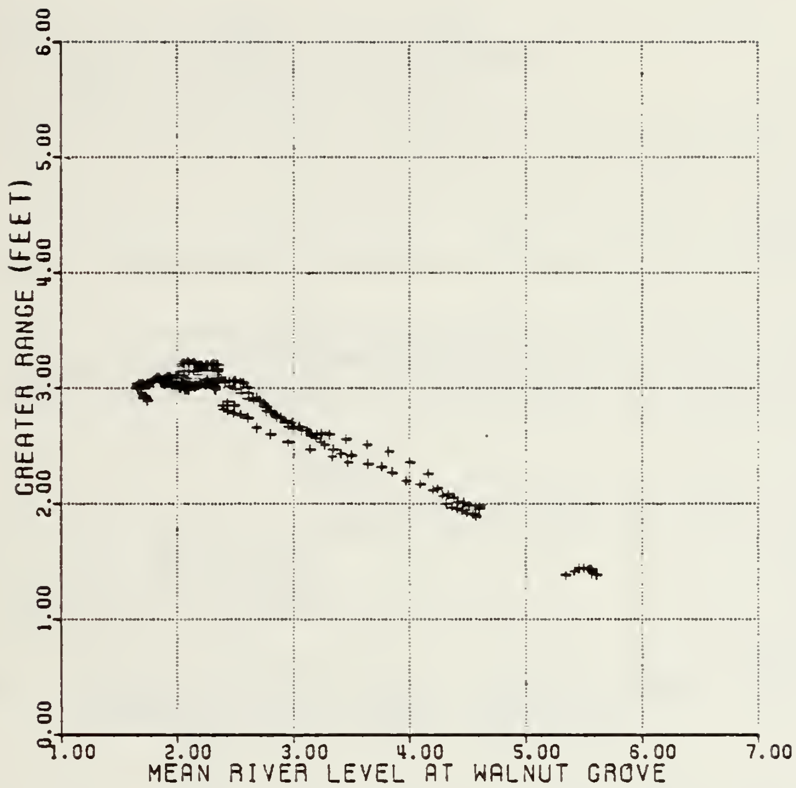


Figure 15: 19-YEAR GREATER RANGE RELATIVE TO MEAN RIVER LEVEL (NGVD) FROM 28-DAY COMPARISONS OVER THE STUDY PERIOD AT WALNUT GROVE.

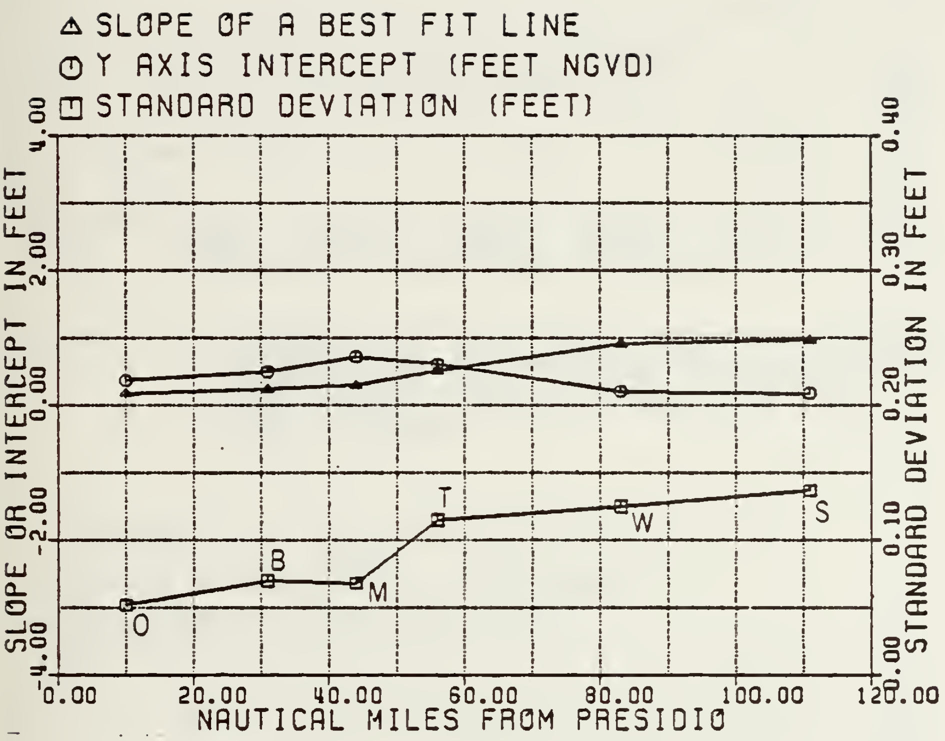


Figure 16. VARIABILITY OF 19-YEAR MEAN TIDE LEVELS RELATIVE TO MEAN RIVER LEVELS FROM 28-DAY OBSERVATIONS OVER THE STUDY PERIOD.

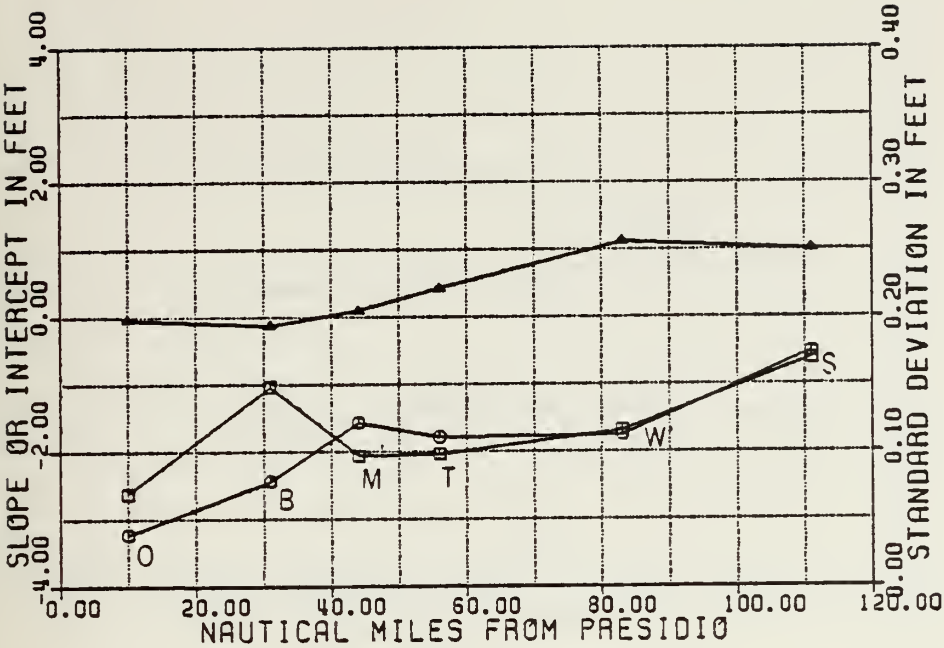


Figure 17. VARIABILITY OF 19-YEAR MEAN LOWER LOW WATERS RELATIVE TO MEAN RIVER LEVELS FROM 28-DAY OBSERVATIONS OVER THE STUDY PERIOD.

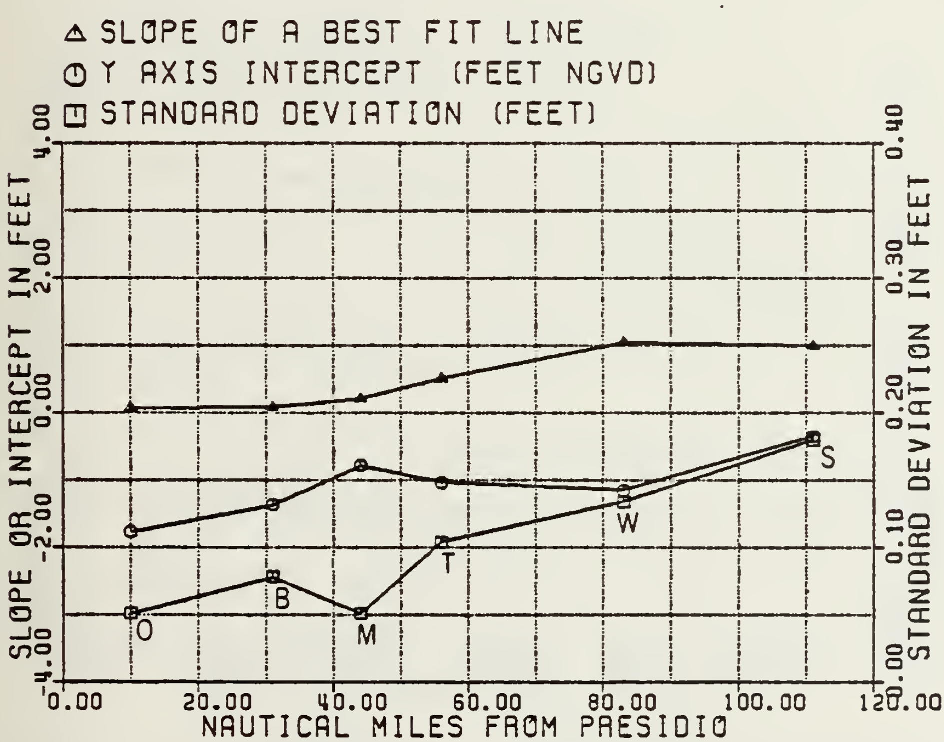


Figure 18. VARIABILITY OF 19-YEAR MEAN LOW WATERS RELATIVE TO MEAN RIVER LEVELS FROM 28-DAY OBSERVATIONS OVER THE STUDY PERIOD.

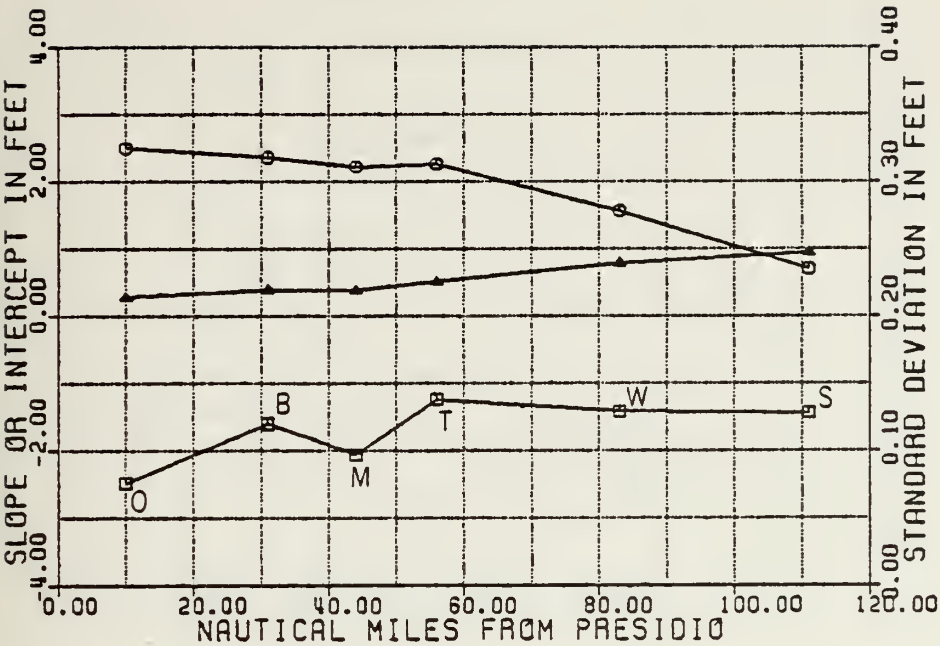


Figure 19. VARIABILITY OF 19-YEAR MEAN HIGH WATERS RELATIVE TO MEAN RIVER LEVELS FROM 28-DAY OBSERVATIONS OVER THE STUDY PERIOD.

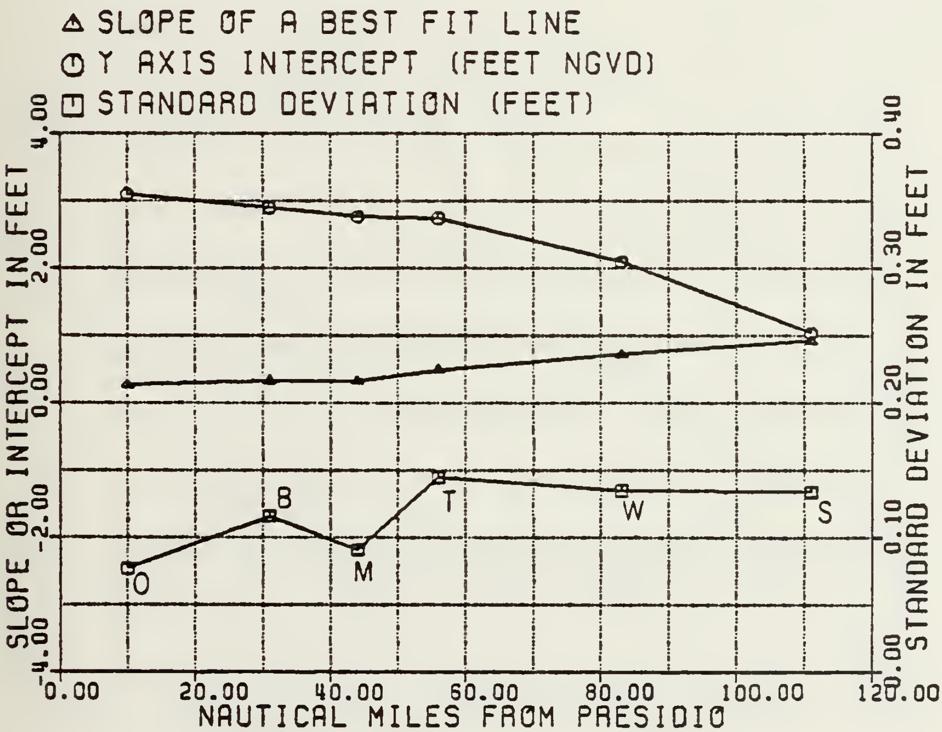


Figure 20. VARIABILITY OF 19-YEAR MEAN HIGHER HIGH WATERS RELATIVE TO MEAN RIVER LEVELS FROM 28-DAY OBSERVATIONS OVER THE STUDY PERIOD.

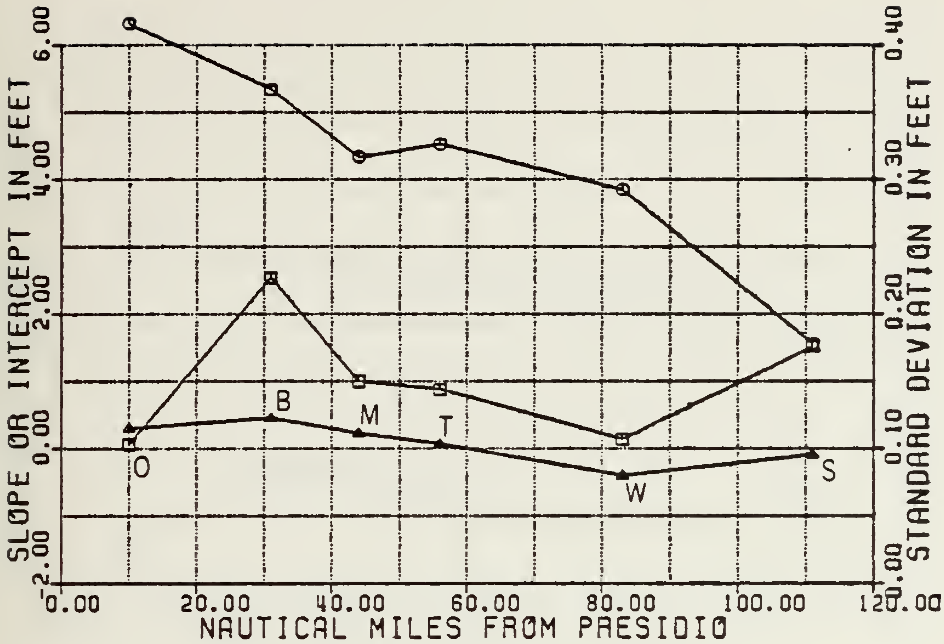


Figure 21. VARIABILITY OF 19-YEAR GREATER RANGES RELATIVE TO MEAN RIVER LEVELS FROM 28-DAY OBSERVATIONS OVER THE STUDY PERIOD.

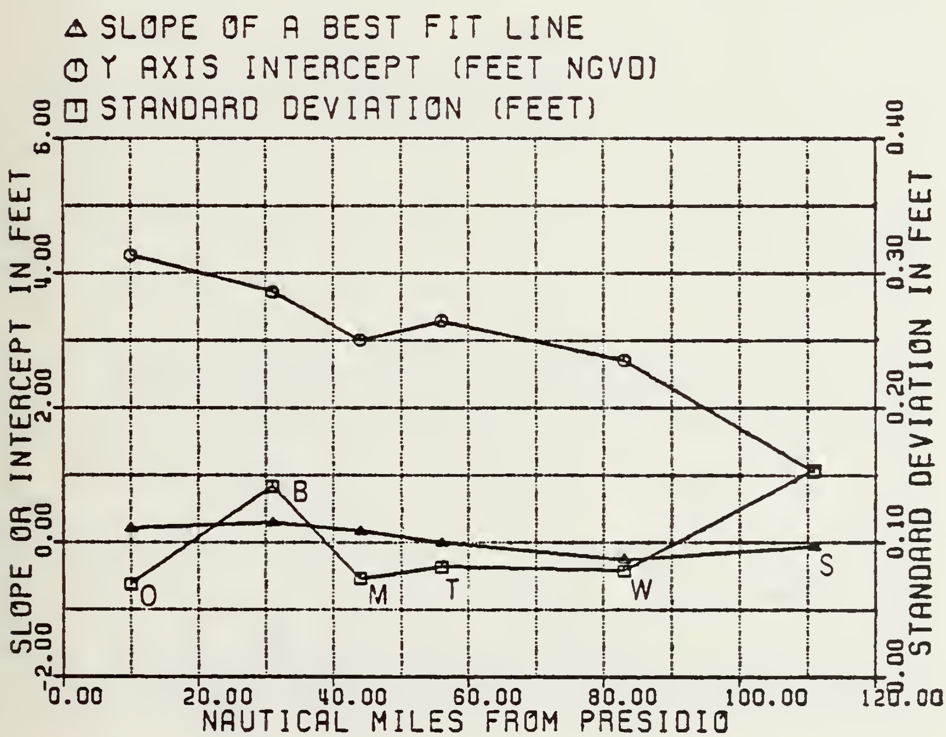


Figure 22. VARIABILITY OF 19-YEAR MEAN RANGE RELATIVE TO MEAN RIVER LEVELS FROM 28-DAY OBSERVATIONS OVER THE STUDY PERIOD.

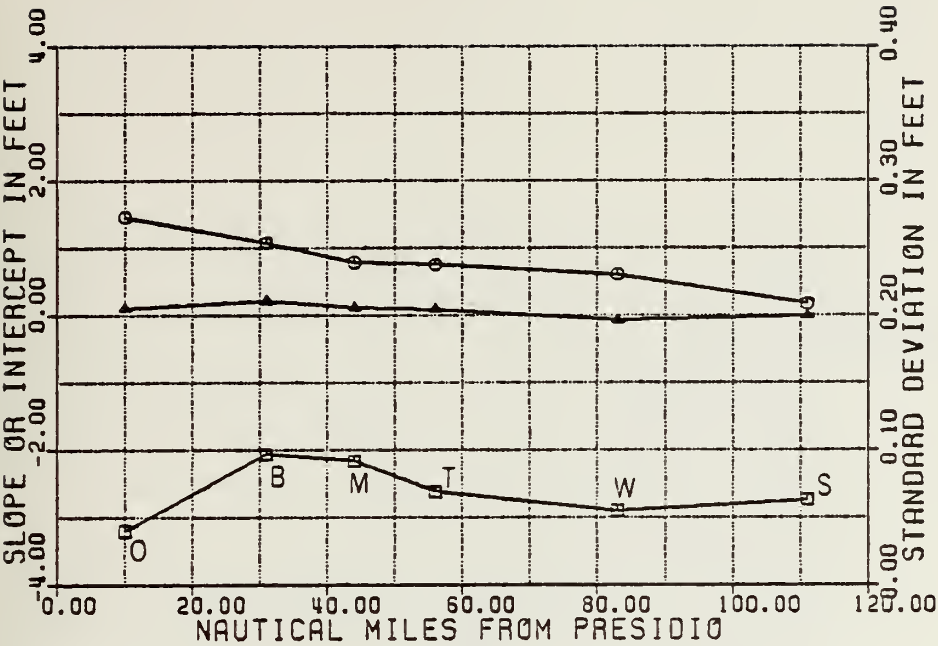


Figure 23. VARIABILITY OF 19-YEAR DIURNAL LOW INEQUALITIES RELATIVE TO MEAN RIVER LEVELS FROM 28-DAY OBSERVATIONS OVER THE STUDY PERIOD.

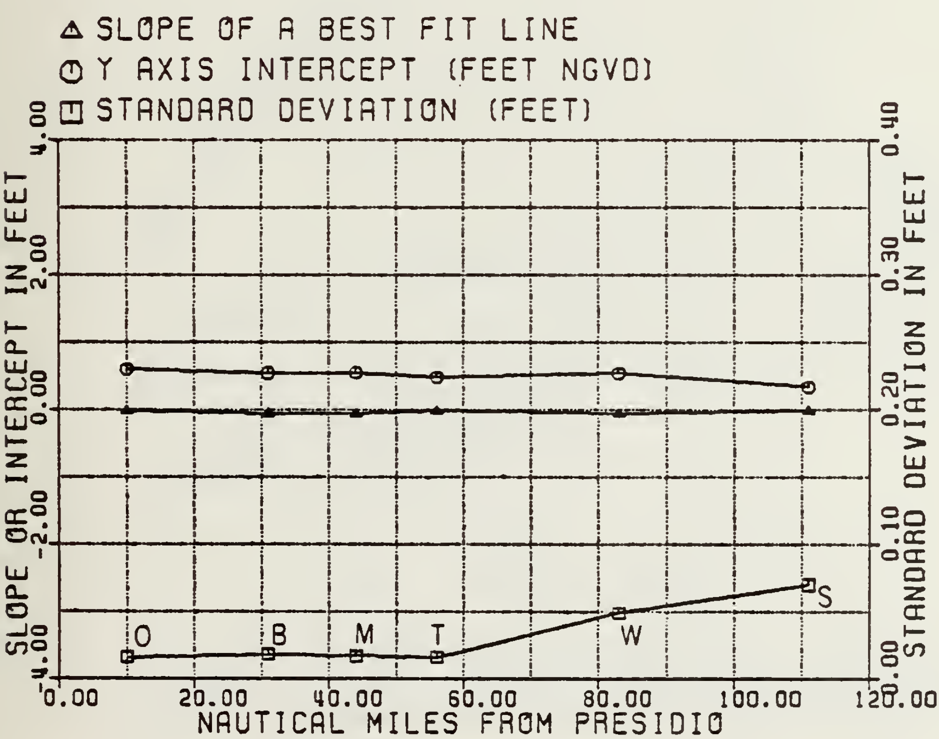


Figure 24. VARIABILITY OF 19-YEAR DIURNAL HIGH INEQUALITIES RELATIVE TO MEAN RIVER LEVELS FROM 28-DAY OBSERVATIONS OVER THE STUDY PERIOD.

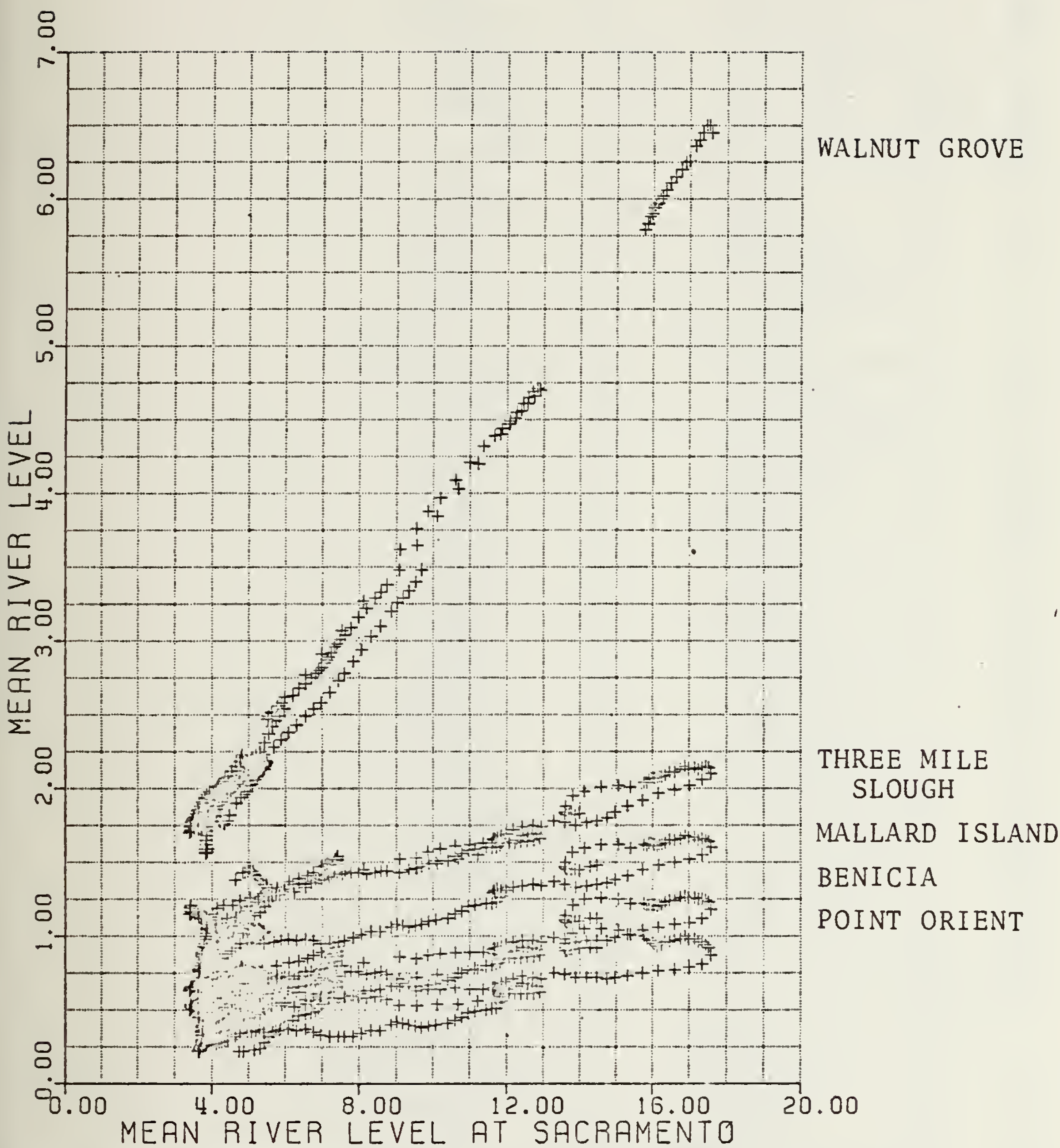


Figure 25. RELATION BETWEEN MEAN RIVER LEVEL (NGVD) AT SACRAMENTO AND AT OTHER RIVER STATIONS FROM 28-DAY OBSERVATIONS OVER THE STUDY PERIOD. SEE FIGURE 20.

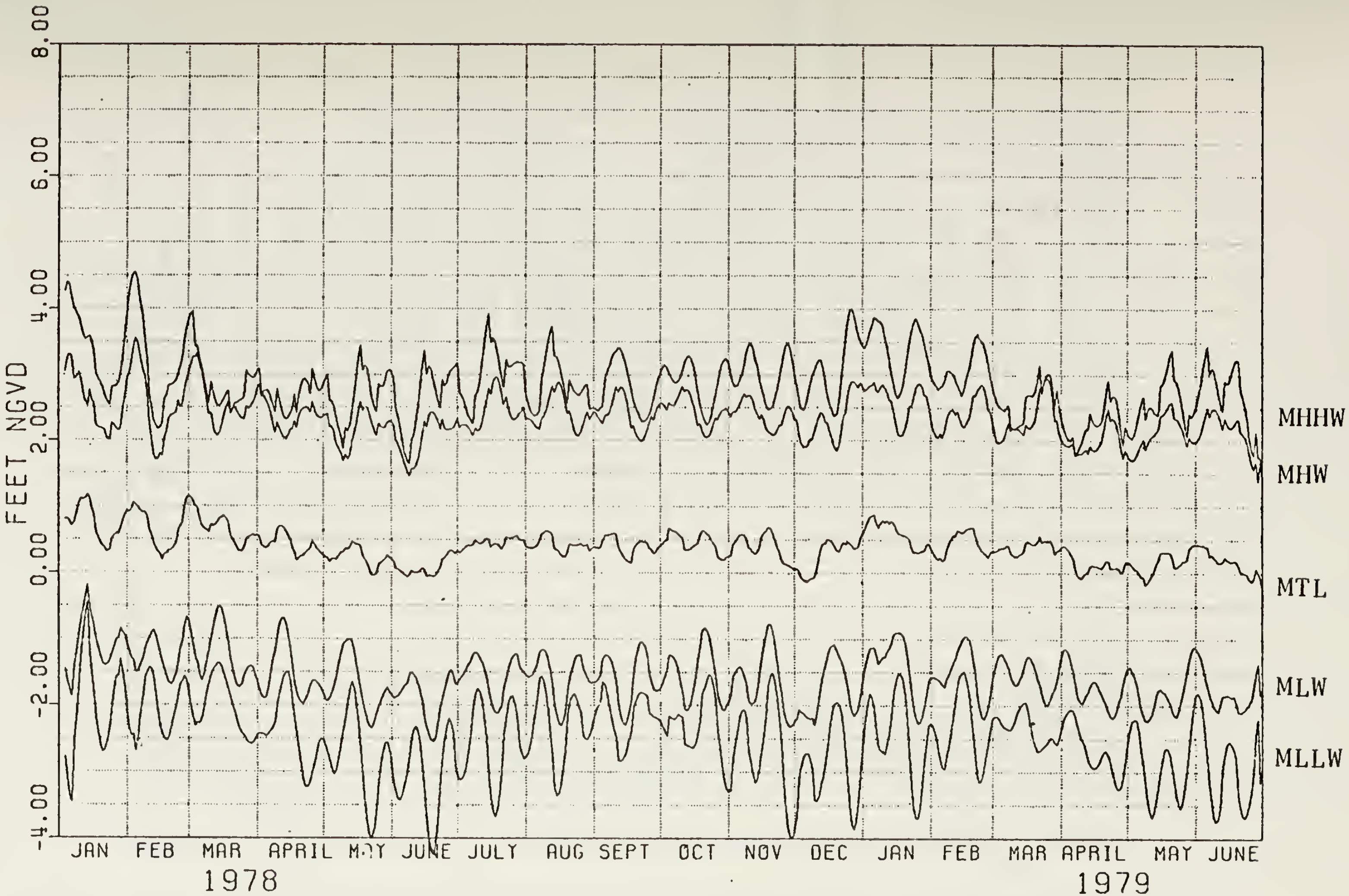


Figure 26. TIDAL DATUMS AT PRESIDIO COMPUTED WITH A 7-DAY RUNNING MEAN.

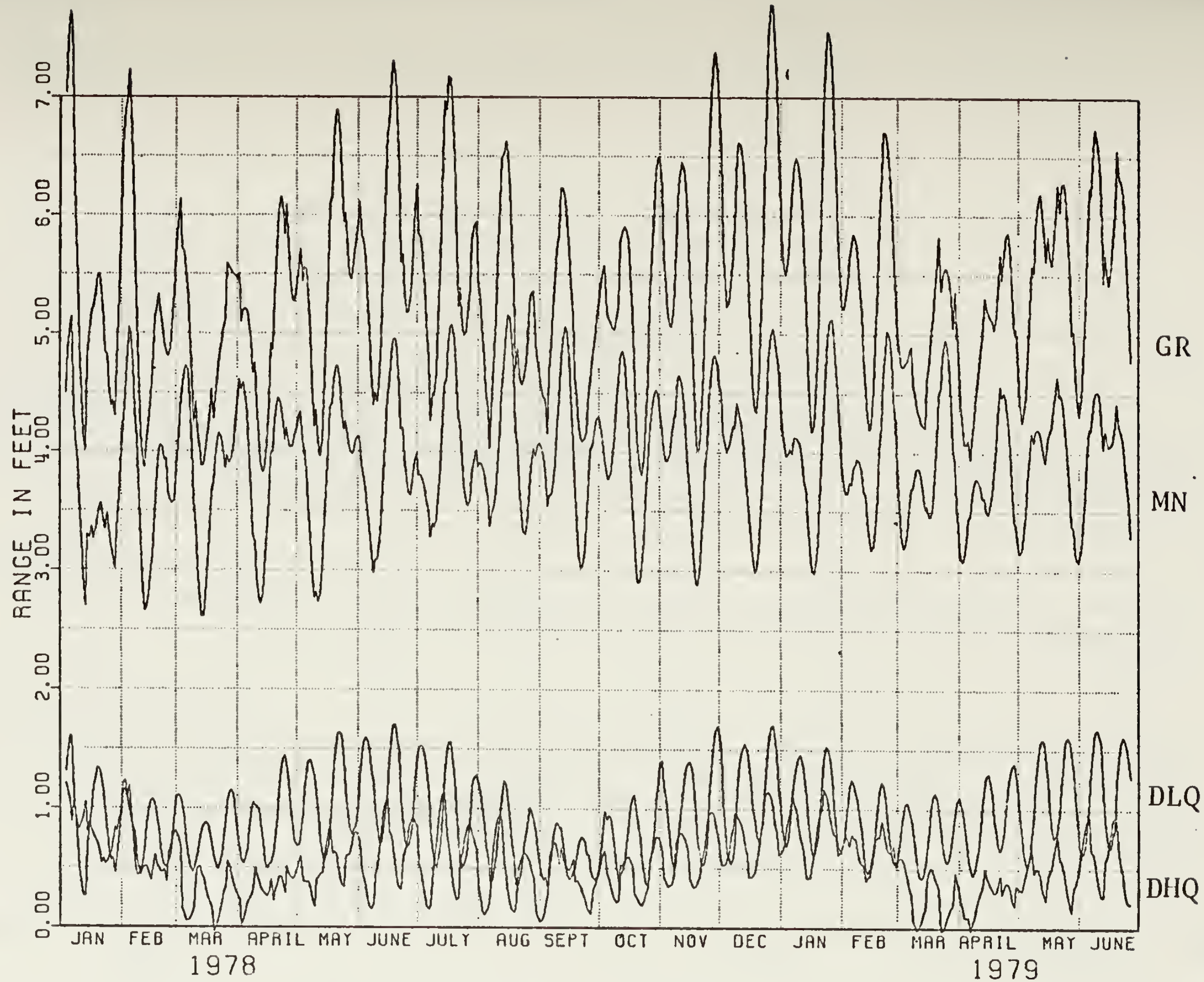


Figure 27. TIDAL RANGES AT PRESIDIO COMPUTED WITH A 7-DAY RUNNING MEAN.

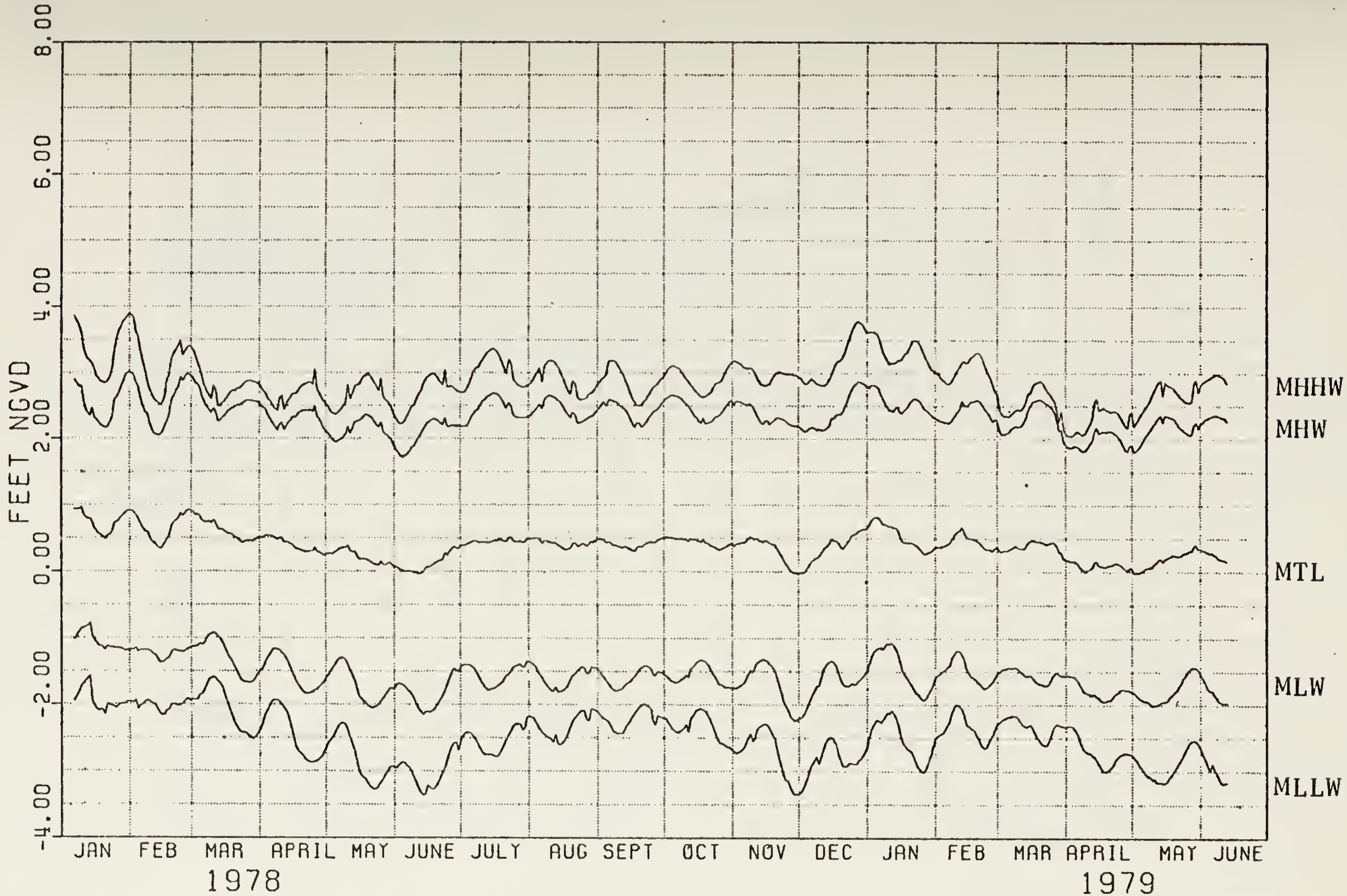


Figure 28. TIDAL DATUMS AT PRESIDIO COMPUTED WITH A 14-DAY RUNNING MEAN.

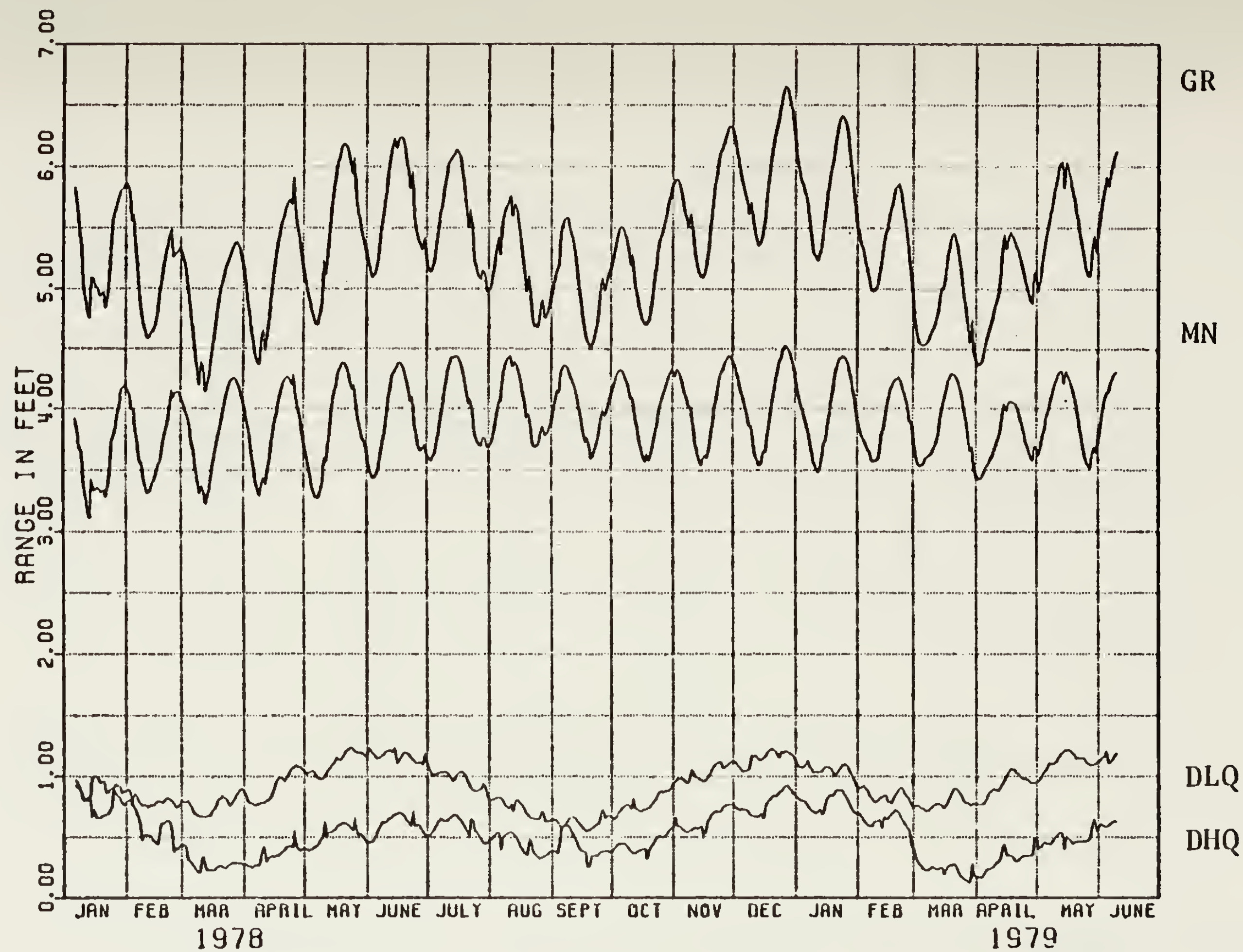


Figure 29. TIDAL RANGES AT PRESIDIO COMPUTED WITH A 14-DAY RUNNING MEAN.

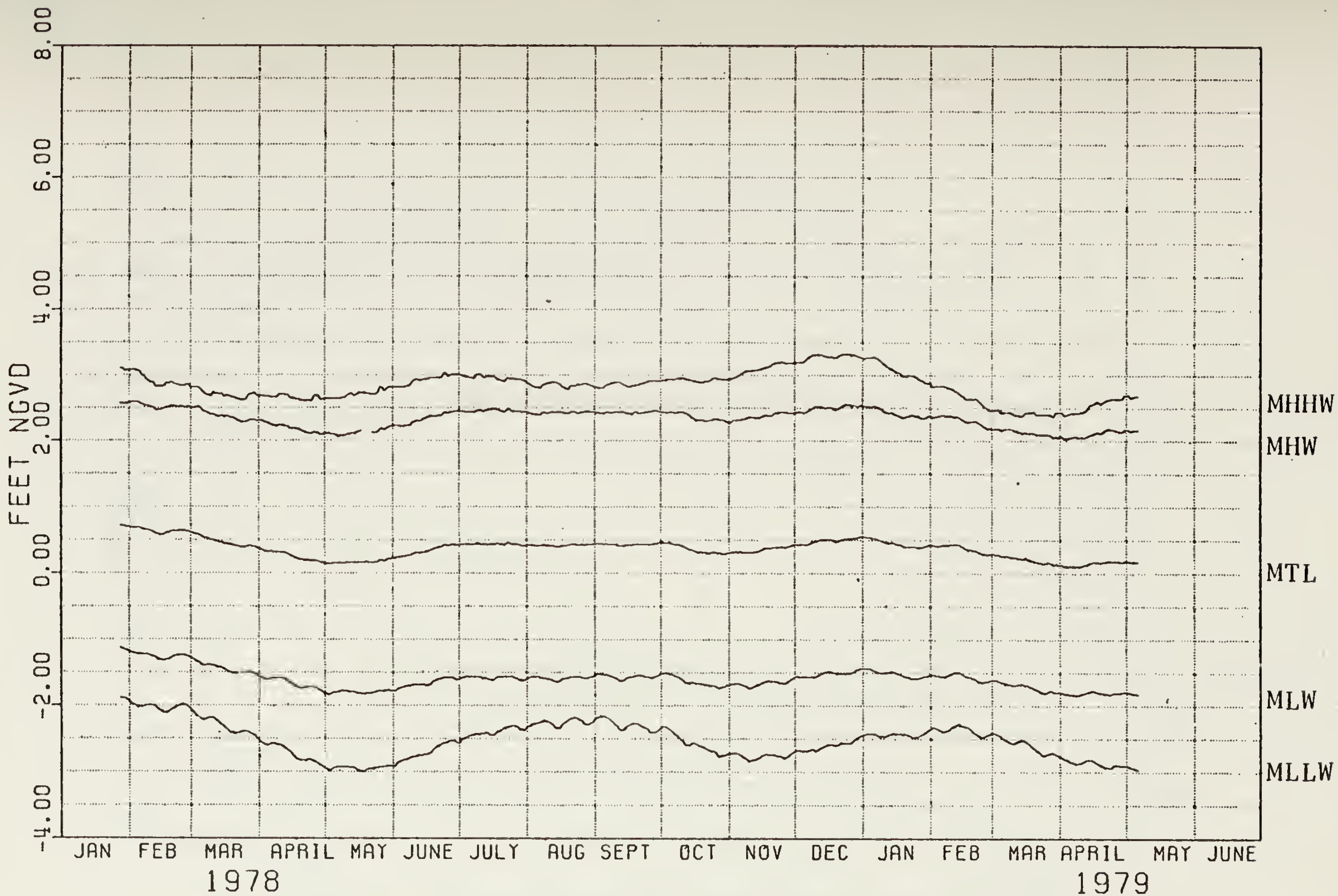


Figure 30. TIDAL DATUMS AT PRESIDIO FROM A 56-DAY RUNNING MEAN.

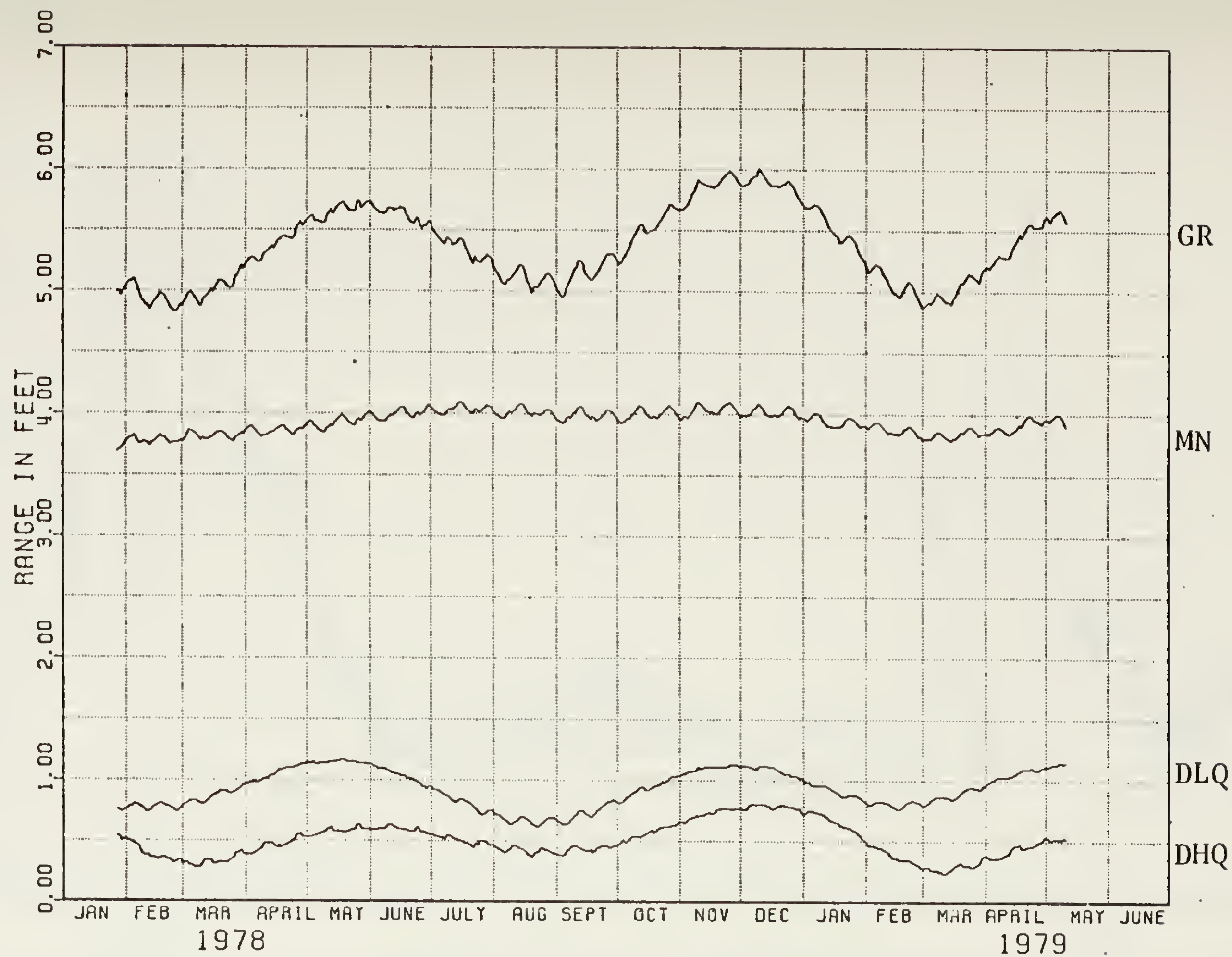


Figure 31. TIDAL RANGES AT PRESIDIO COMPUTED WITH A 56-DAY RUNNING MEAN.

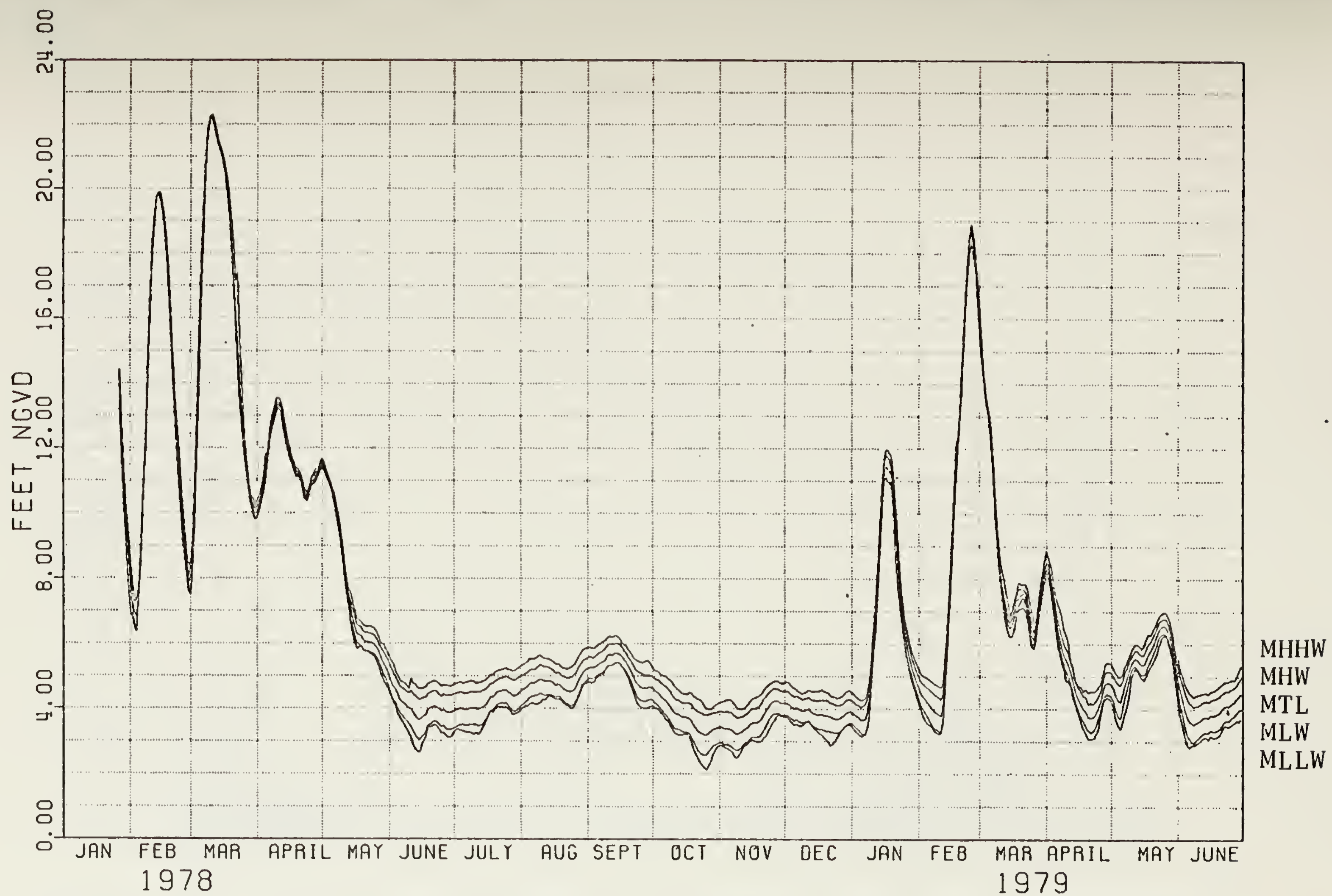


Figure 32. 19-YEAR TIDAL DATUMS AT SACRAMENTO FROM 7-DAY COMPARISONS.

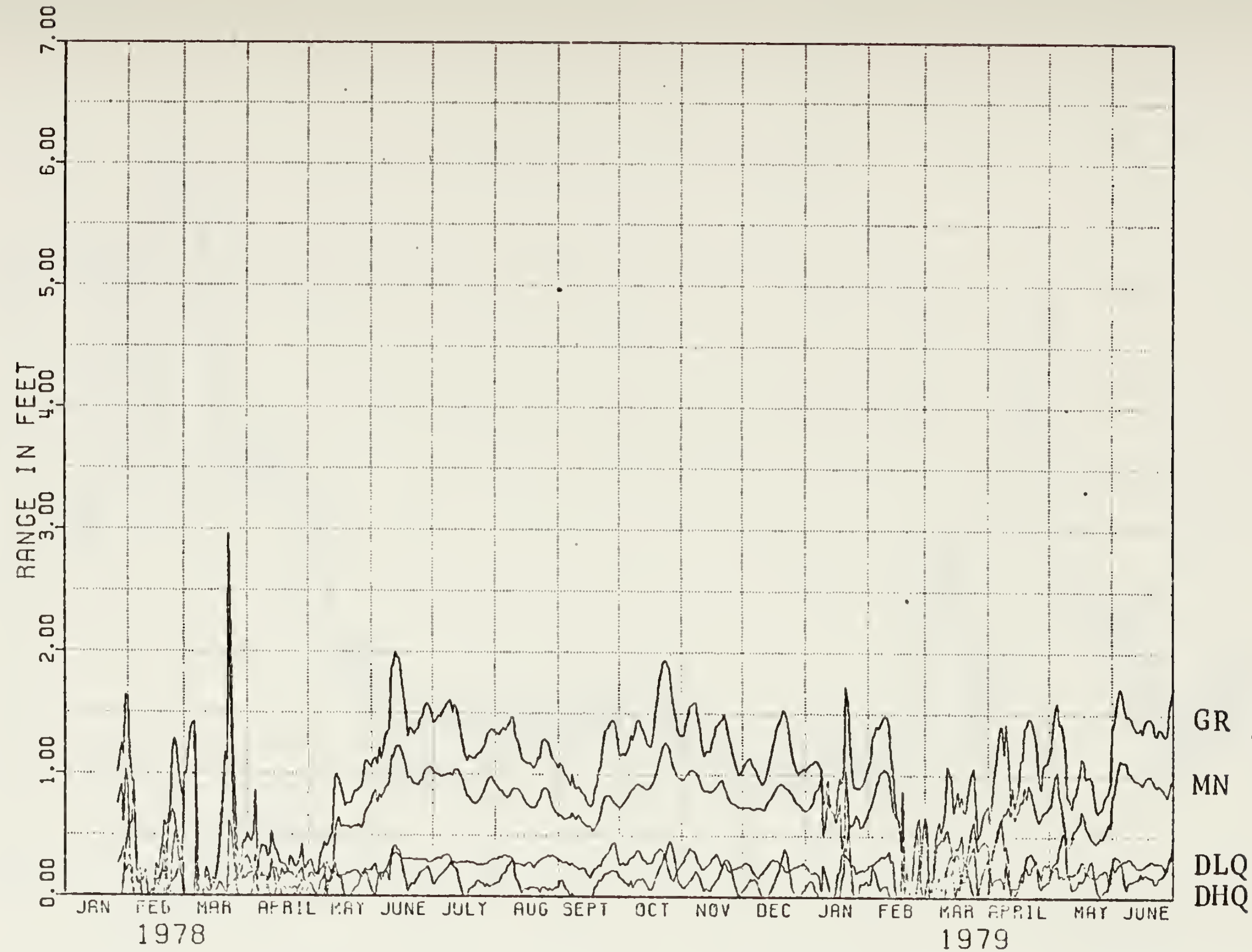


Figure 33. 19-YEAR TIDAL RANGES AT SACRAMENTO FROM 7-DAY COMPARISONS.

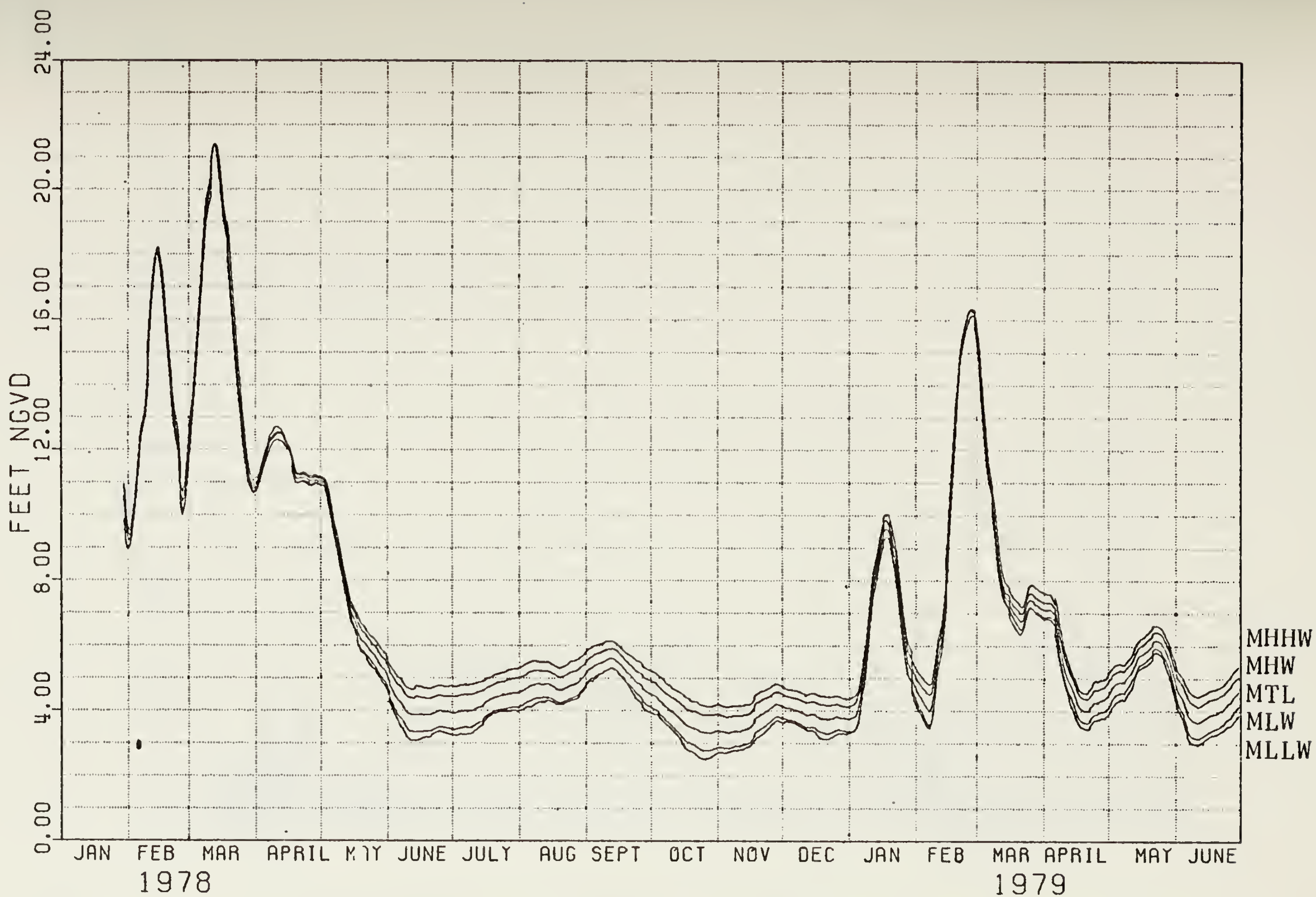


Figure 34. 19-YEAR TIDAL DATUMS AT SACRAMENTO FROM 14-DAY COMPARISONS.

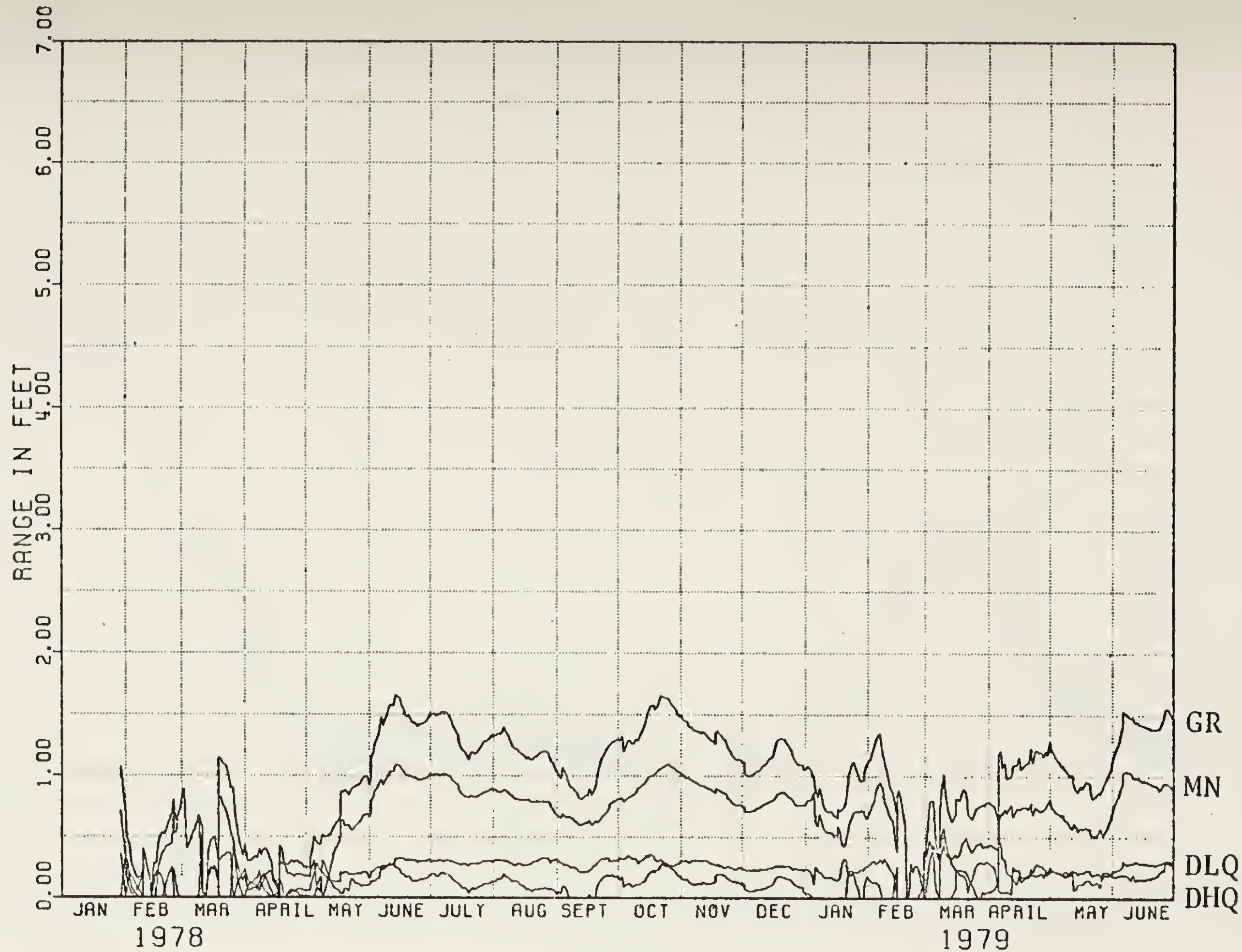


Figure 35. 19-YEAR TIDAL RANGES AT SACRAMENTO FROM 14-DAY COMPARISONS.

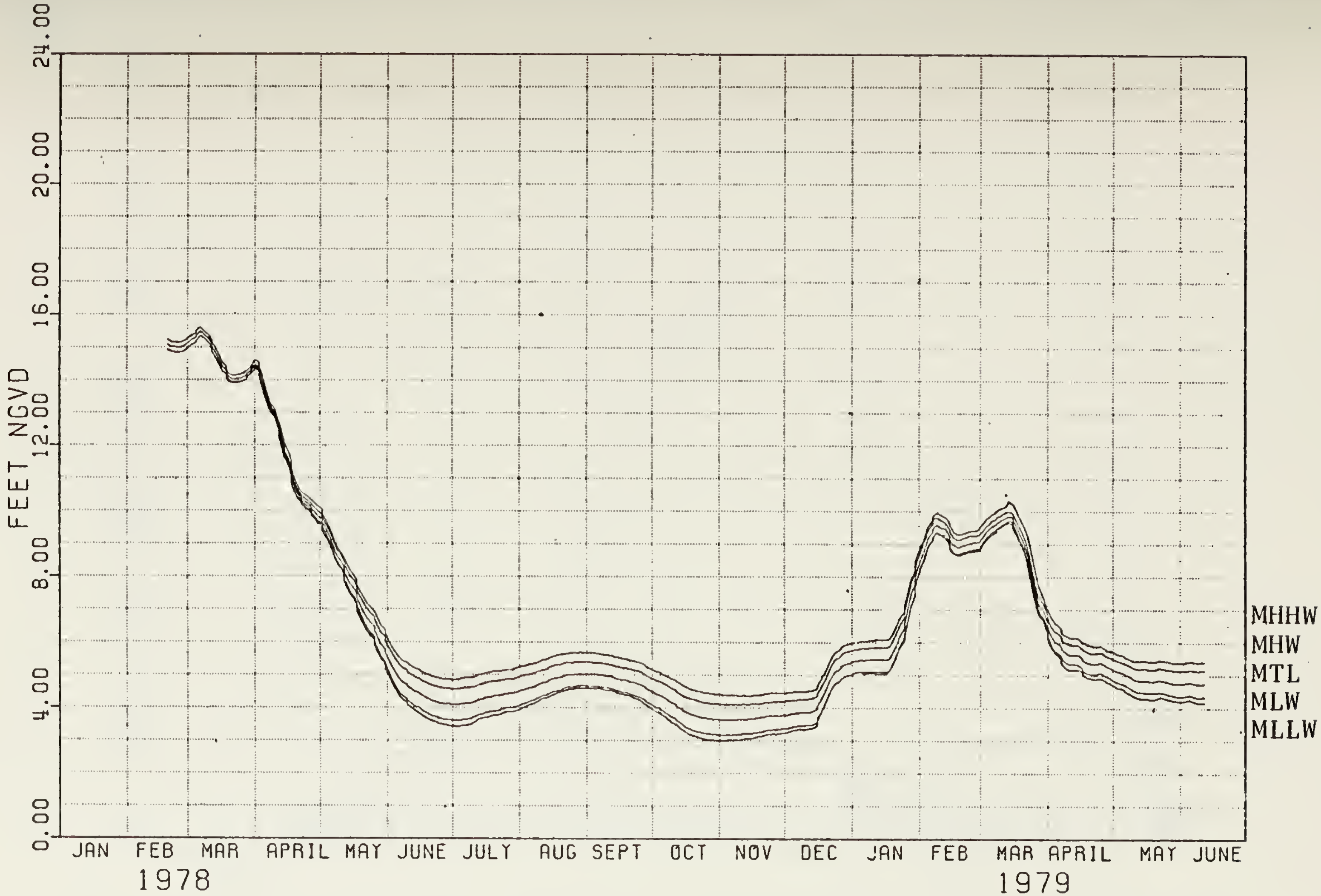


Figure 36. 19-YEAR TIDAL DATUMS AT SACRAMENTO FROM 56-DAY COMPARISONS.

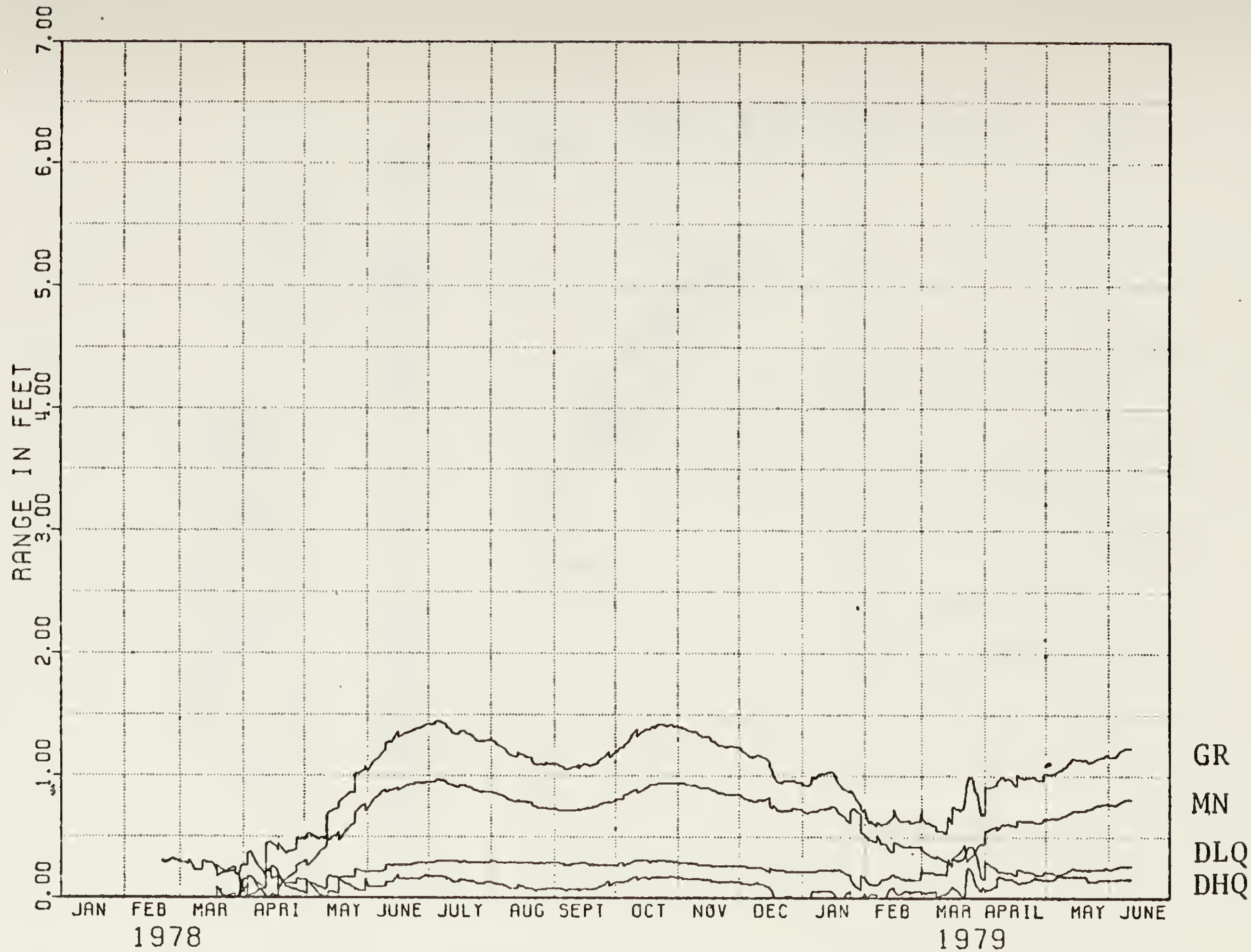


Figure 37. 19-YEAR TIDAL RANGES AT SACRAMENTO FROM 56-DAY COMPARISONS.

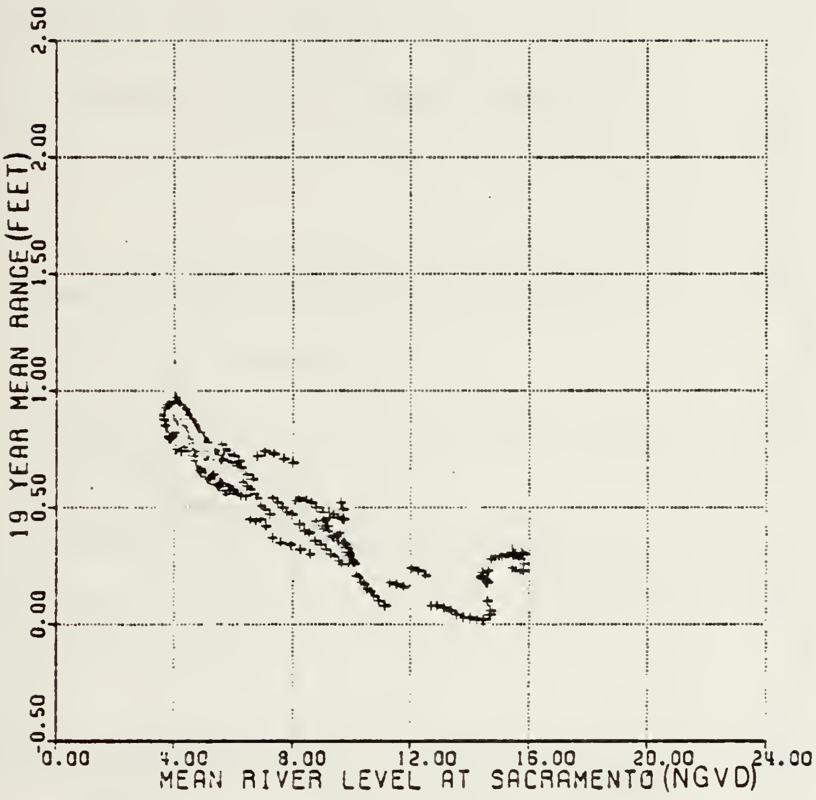
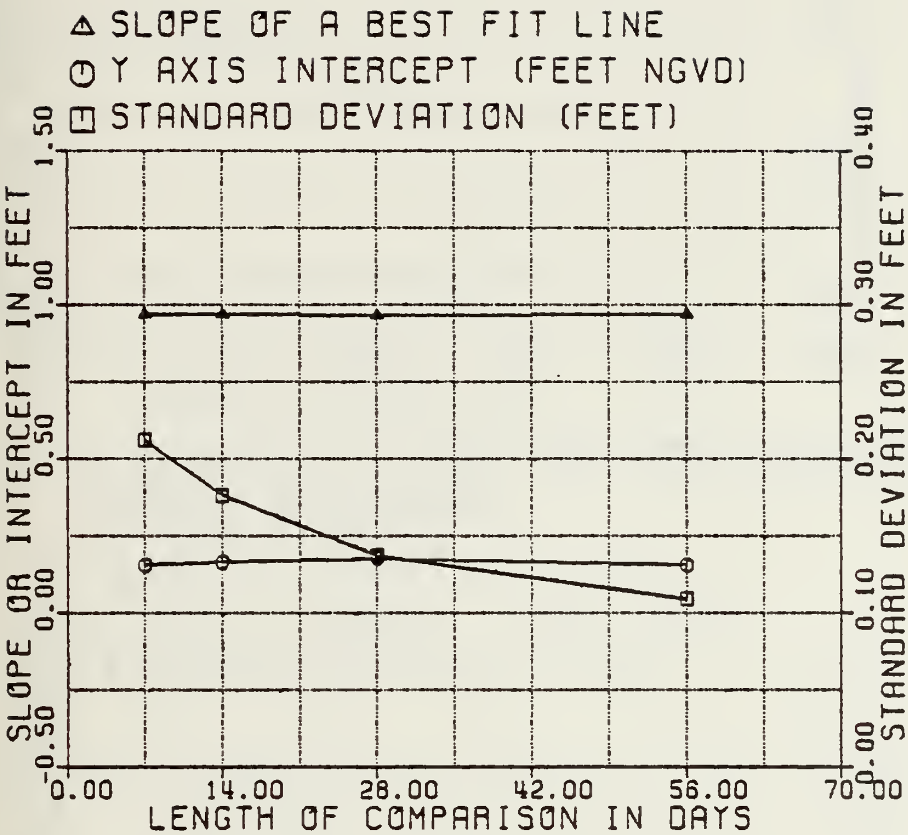
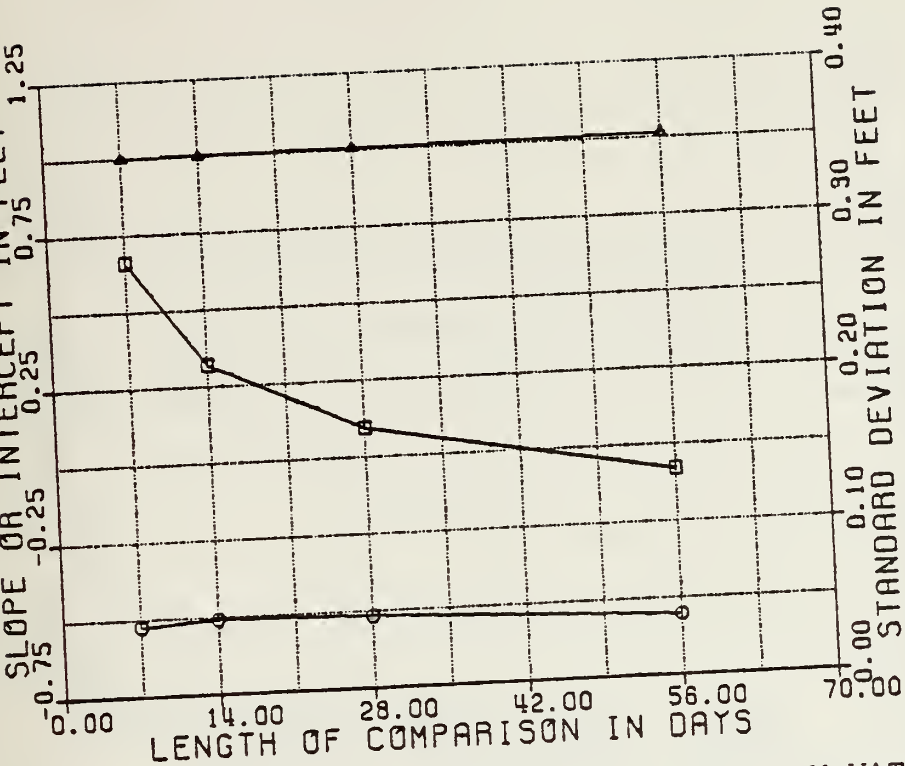


Figure 38. 19-YEAR MEAN RANGE AT SACRAMENTO RELATIVE TO MEAN RIVER LEVEL FROM 56-DAY COMPARISONS.



'igure 39. VARIABILITY OF 19-YEAR MEAN TIDE LEVELS RELATIVE TO MEAN RIVER LEVELS WITH COMPARISON INTERVAL AT SACRAMENTO.



gure 40. VARIABILITY OF 19-YEAR MEAN LOWER LOW WATERS RELATIVE TO MEAN RIVER LEVELS WITH COMPARISON INTERVAL AT SACRAMENTO.

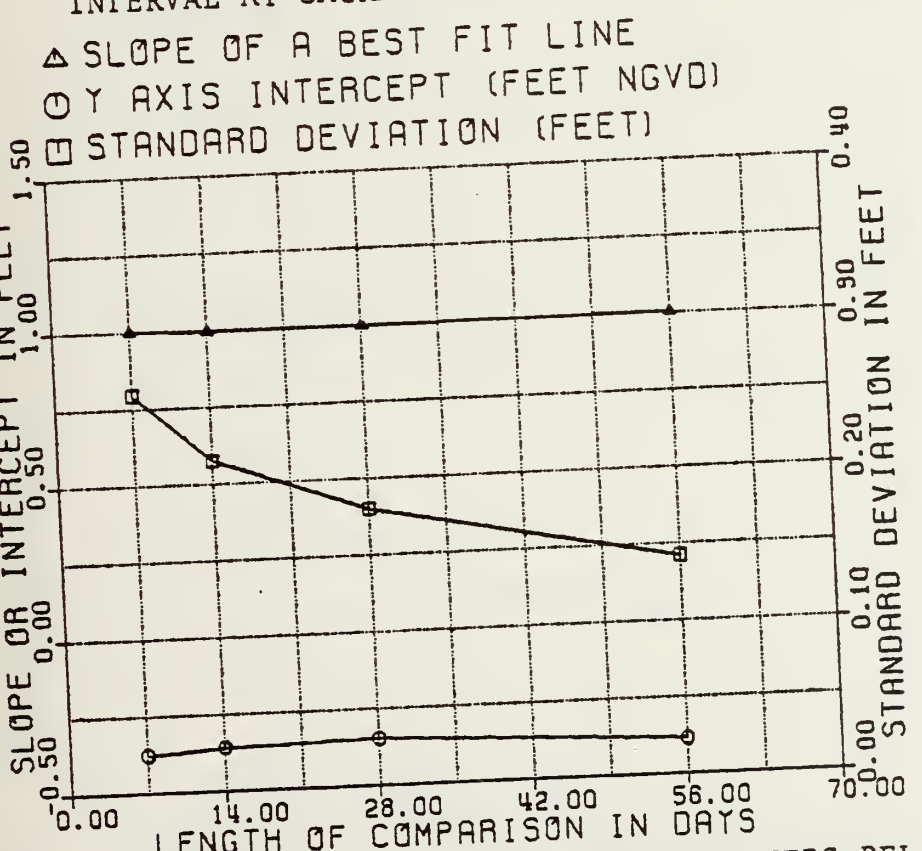


Figure 41. VARIABILITY OF 19-YEAR MEAN LOW WATERS RELATIVE TO MEAN RIVER LEVELS WITH COMPARISON INTERVAL AT SACRAMENTO.

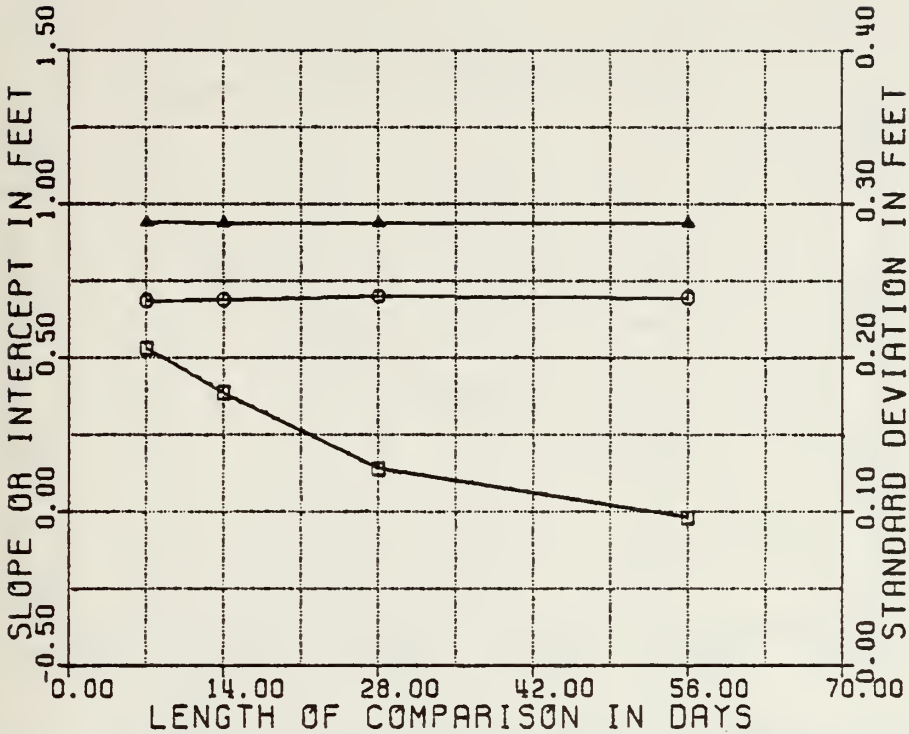


Figure 42. VARIABILITY OF 19-YEAR MEAN HIGH WATERS RELATIVE TO MEAN RIVER LEVELS WITH COMPARISON INTERVAL AT SACRAMENTO.

△ SLOPE OF A BEST FIT LINE
○ Y AXIS INTERCEPT (FEET NGVD)
□ STANDARD DEVIATION (FEET)

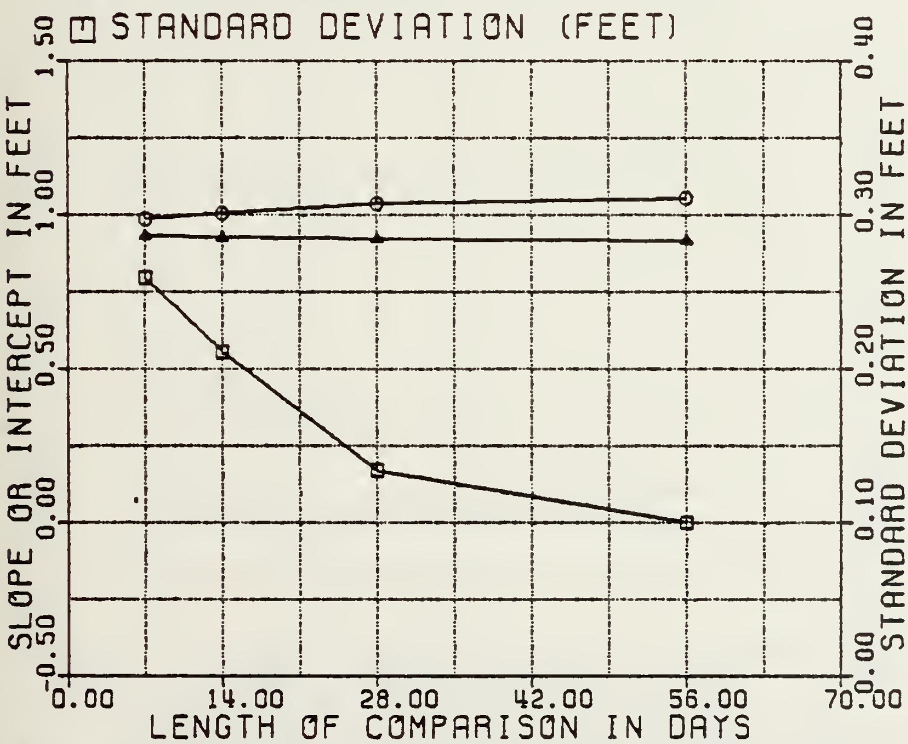


Figure 43. VARIABILITY OF 19-YEAR MEAN HIGHER HIGH WATERS RELATIVE TO MEAN RIVER LEVELS WITH COMPARISON INTERVAL AT SACRAMENTO.

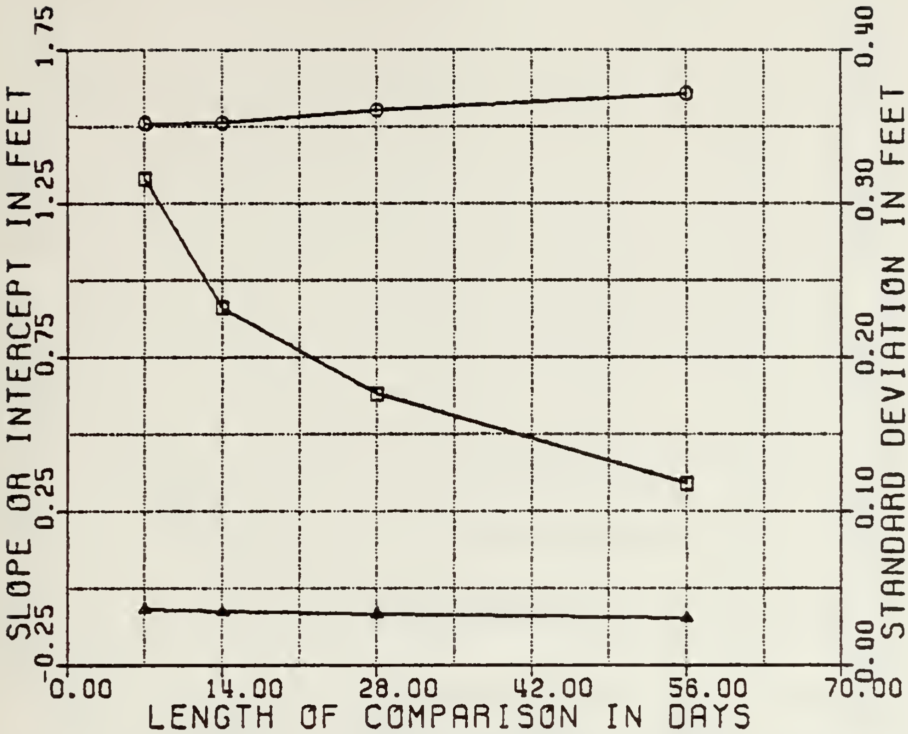


Figure 44. VARIABILITY OF 19-YEAR GREATER RANGES RELATIVE TO MEAN RIVER LEVELS WITH COMPARISON INTERVALS AT SACRAMENTO.

△ SLOPE OF A BEST FIT LINE
○ Y AXIS INTERCEPT (FEET NGVD)
□ STANDARD DEVIATION (FEET)

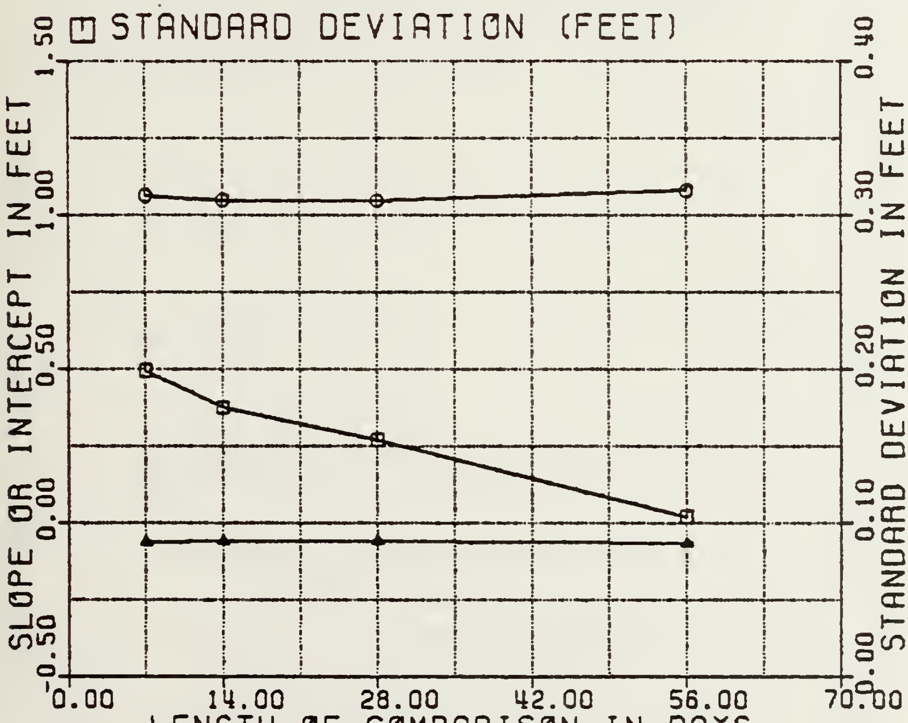


Figure 45. VARIABILITY OF 19-YEAR MEAN RANGES RELATIVE TO MEAN RIVER LEVELS WITH COMPARISON INTERVAL AT SACRAMENTO.

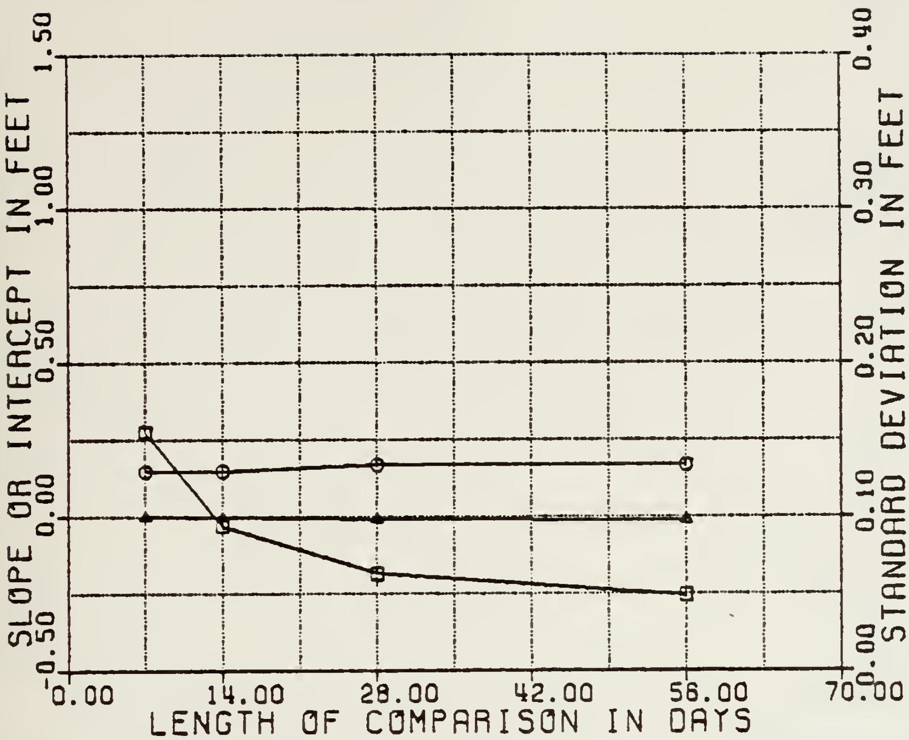


Figure 46. VARIABILITY OF 19-YEAR DIURNAL LOW INEQUALITIES RELATIVE TO MEAN RIVER LEVELS WITH COMPARISON INTERVAL AT SACRAMENTO.

△ SLOPE OF A BEST FIT LINE

○ Y AXIS INTERCEPT (FEET NGVD)

□ STANDARD DEVIATION (FEET)

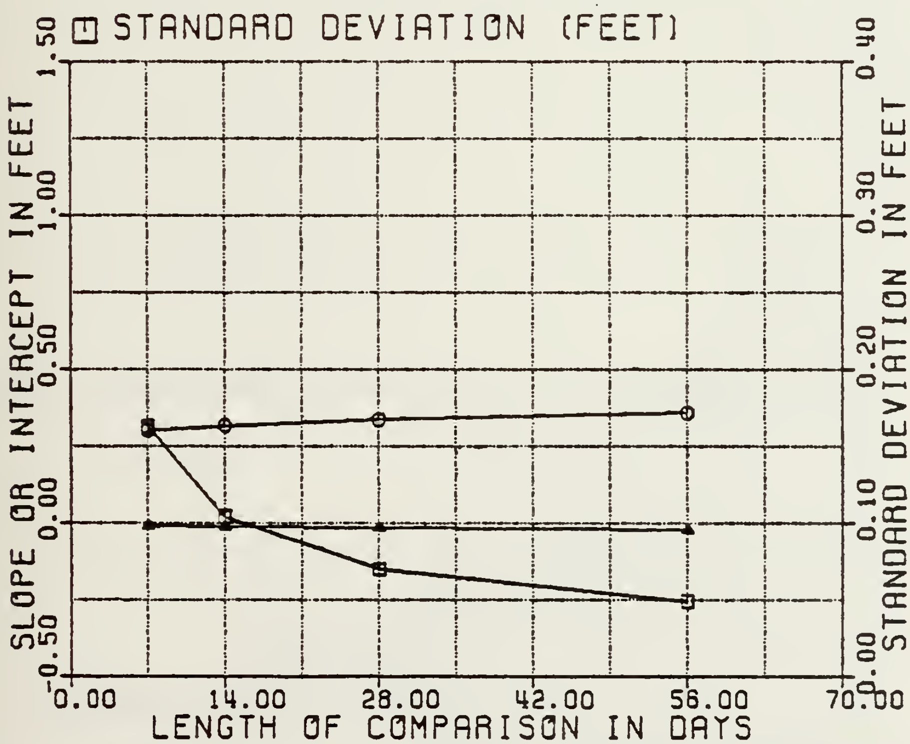
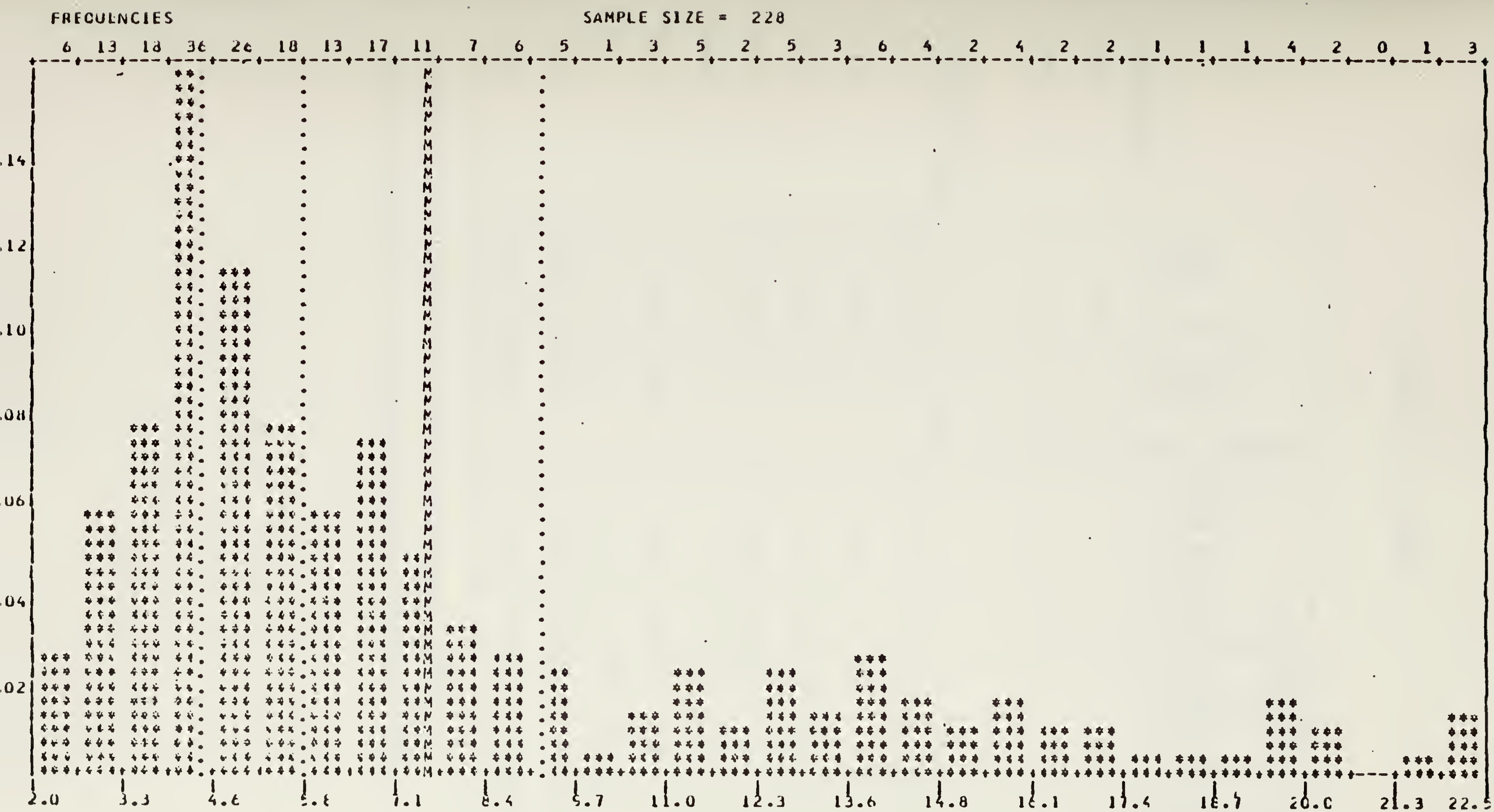


Figure 47. VARIABILITY OF 19-YEAR DIURNAL HIGH INEQUALITIES RELATIVE TO MEAN RIVER LEVELS WITH COMPARISON INTERVAL AT SACRAMENTO.



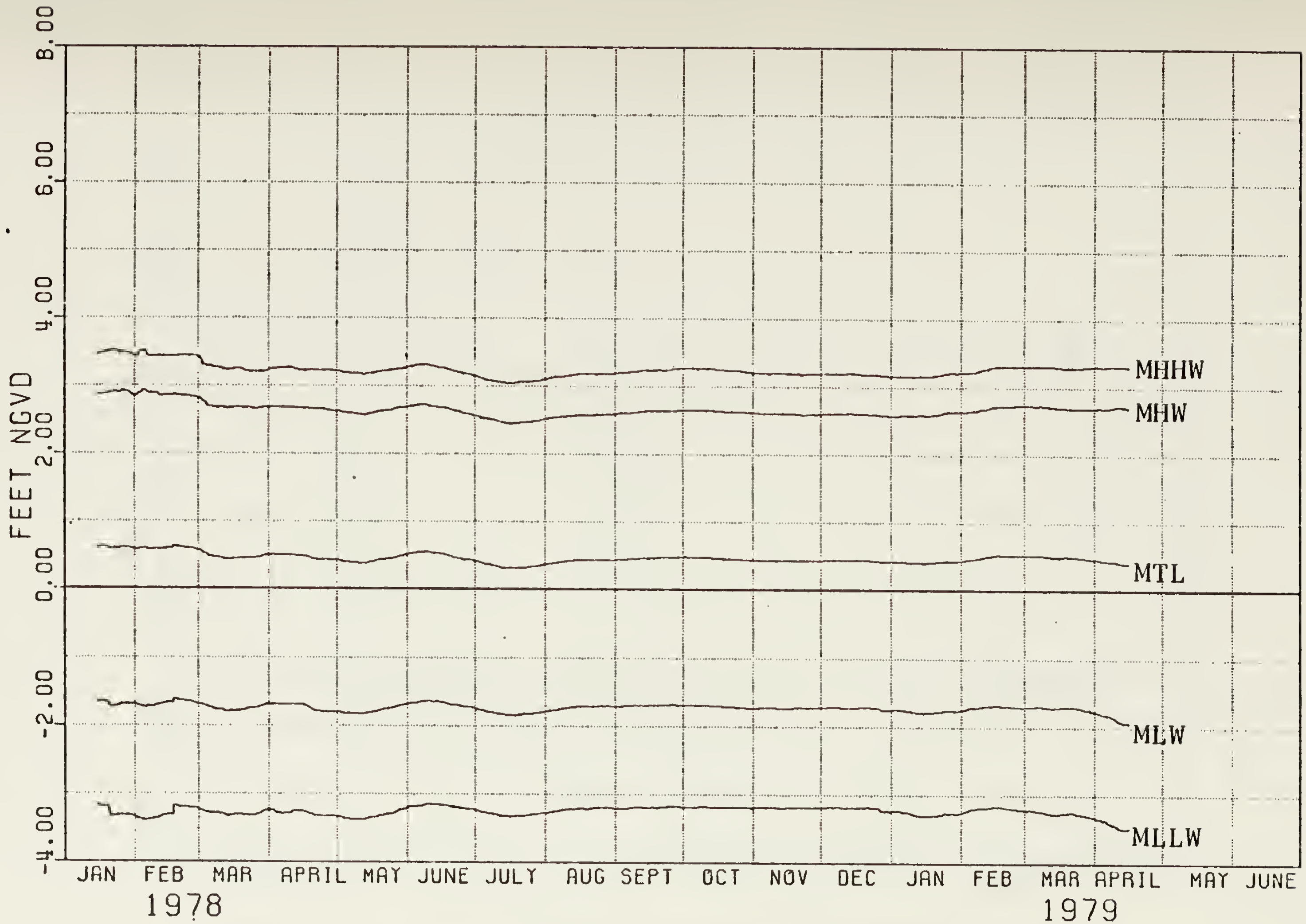
CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	7.544954E 00	VARIANCE	2.235133E 01	M3	1.475707E 02	MINIMUM	1.980000E 00
MEDIAN	5.690000E 00	STD DEV	4.727715E 00	M4	2.057201E 03	.10 QUANTILE	3.580000E 00
TRIMEAN	6.189995E 00	COEF VAR	6.266067E-01	SKEWNESS	1.396514E 00	.25 QUANTILE (HINGE)	4.259999E 00
MIDMEAN	5.984365E 00	MEAN DEV	3.346534E 00	KURTOSIS	1.117845E 00	.50 QUANTILE (MEDIAN)	5.690000E 00
MIDRANGE	1.226455E 01	RANGE	2.056555E 01	BETA1	1.456347E 02	.75 QUANTILE (HINGE)	9.119995E 00
GEOM MEAN	6.411249E 00	MIDSPREAD	4.859996E 00	BETA2	2.034171E 03	.90 QUANTILE	1.479000E 01
HARM MEAN	5.584043E 00					MAXIMUM	2.254999E 01

Figure 48. HISTOGRAM OF MONTHLY MEAN RIVER LEVELS (NGVD) AT SACRAMENTO FOR THE EPOCH 1960-1978.

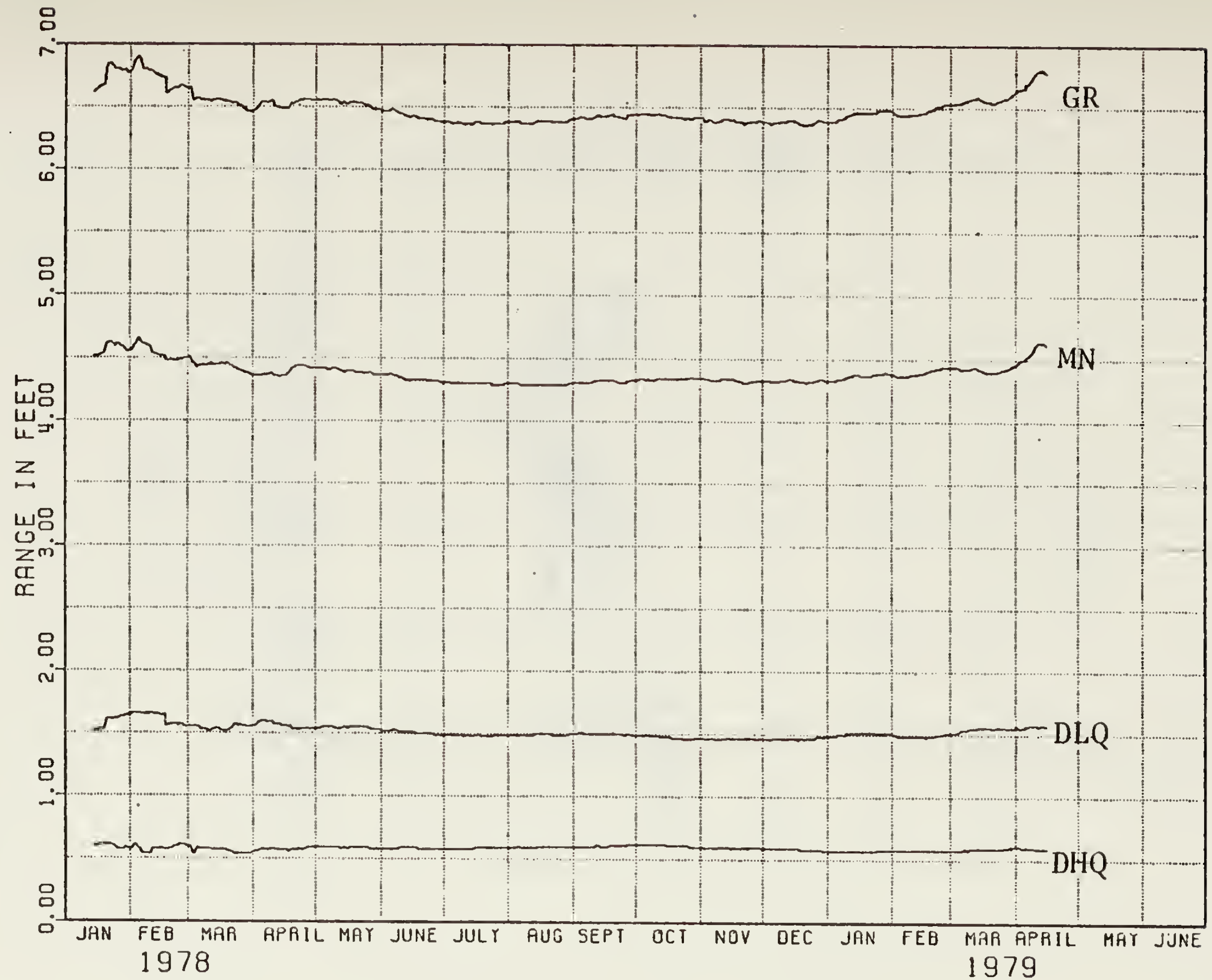
APPENDIX A. GRAPHS

	POINT ORIENT	BENICIA	MALLARD ISLAND	COLLINSVILLE	THREE MILE SLOUGH	WALNUT GROVE	SACRAMENTO			
Time Series							7-DAY COMPARISON	14-DAY COMPARISON	28-DAY COMPARISON	56-DAY COMPARISON
Datums	0-1	B-1	M-1	C-1	T-1	W-1	32	34	11	36
Ranges	0-2	B-2	M-2	C-2	T-2	W-2	33	35	12	37
Scatter Plots										
MTL	0-3	B-3	M-3		T-3	W-3	Q-3	R-3	S-3	V-3
MLLW	0-4	B-4	M-4		T-4	W-4	Q-4	R-4	S-4	V-4
MLW	0-5	B-5	M-5		T-5	W-5	Q-5	R-5	S-5	V-5
MHW	0-6	B-6	M-6		T-6	W-6	Q-6	R-6	S-6	V-6
MHHW	0-7	B-7	M-7		T-7	W-7	Q-7	R-7	S-7	V-7
GR	0-8	B-8	M-8		T-8	W-8	Q-8	R-8	S-8	V-8
MN	0-9	B-9	M-9		T-9	W-9	Q-9	R-9	S-9	V-9
DLQ	0-10	B-10	M-10		T-10	W-10	Q-10	R-10	S-10	V-10
DHQ	0-11	B-11	M-11		T-11	W-11	Q-11	R-11	S-11	V-11

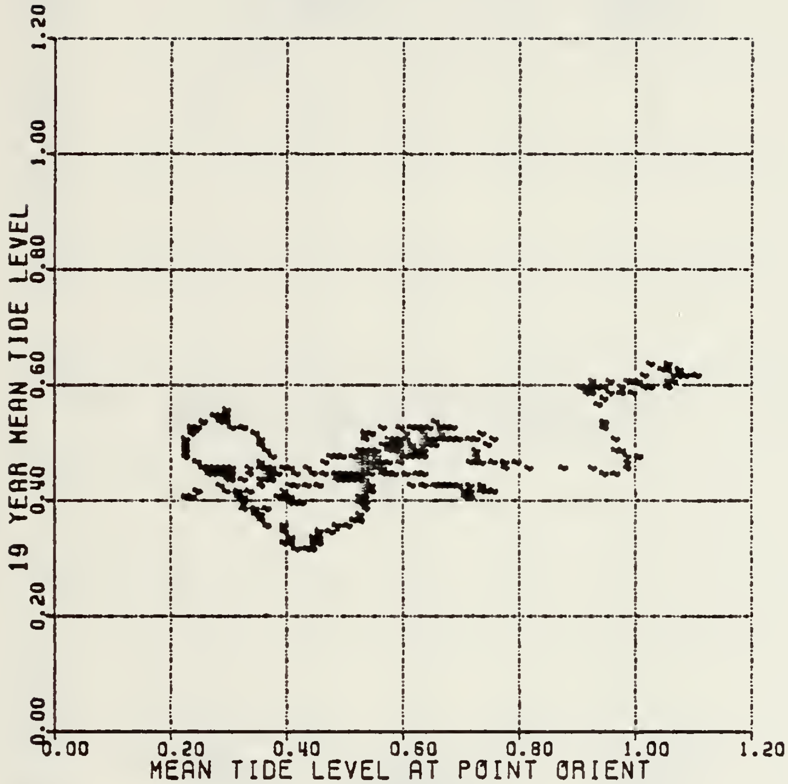
All graphs are computed from 28-day comparisons, except as otherwise indicated. All scatter plots are relative to NGVD.



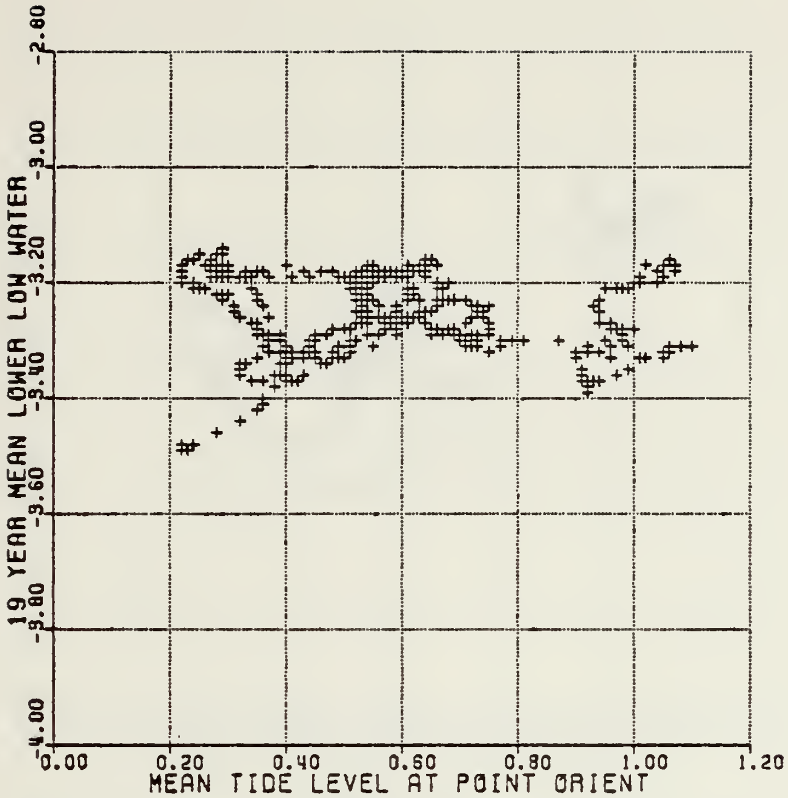
Graph 0-1. 19-YEAR TIDAL DATUMS AT POINT ORIENT.



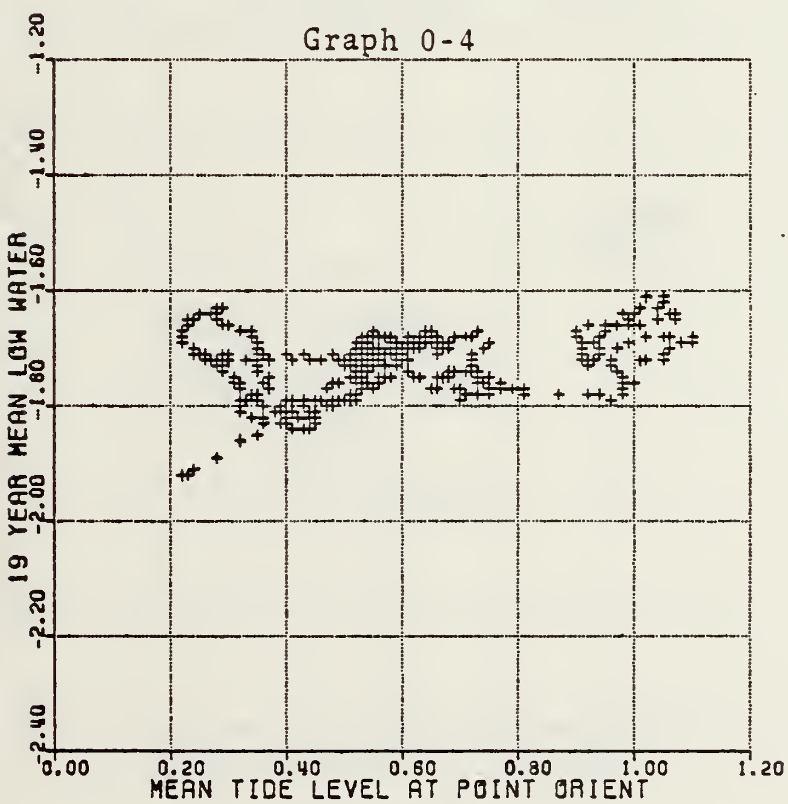
Graph 0-2. 19-YEAR TIDAL RANGES AT POINT ORIENT.


19 YEAR MEAN TIDE LEVEL
0.00
0.20
0.40
0.60
0.80
1.00
1.20
0.00
0.20
0.40
0.60
0.80
1.00
1.20
MEAN TIDE LEVEL AT POINT ORIENT

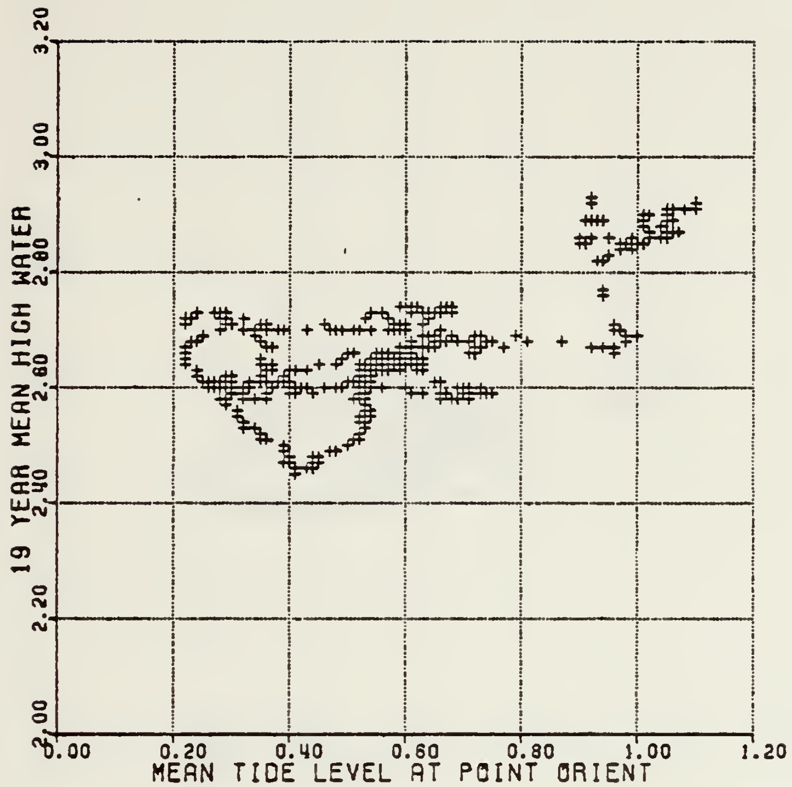
Graph 0-3



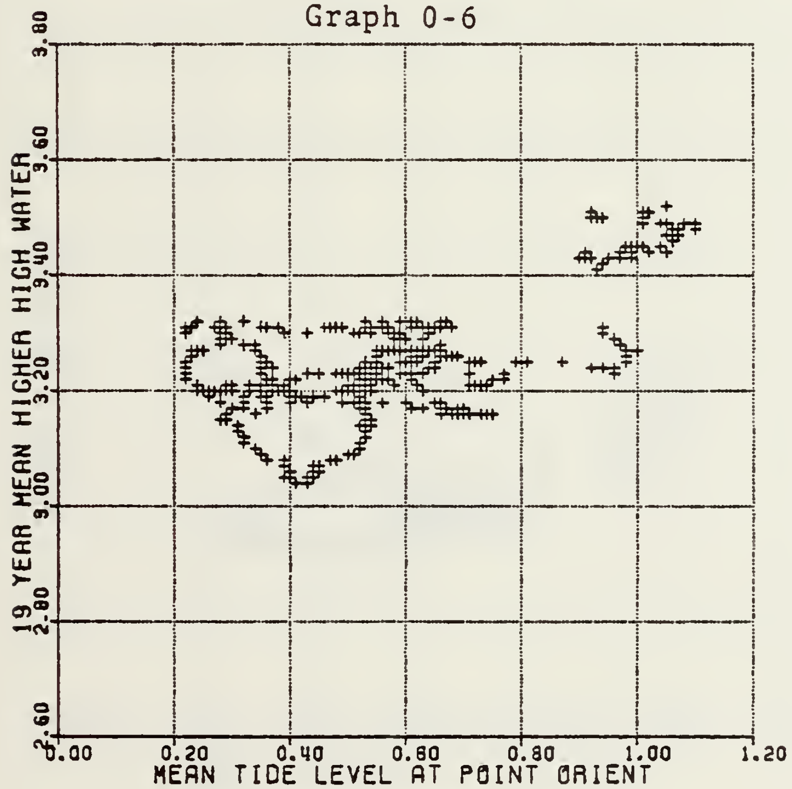
Graph 0-4



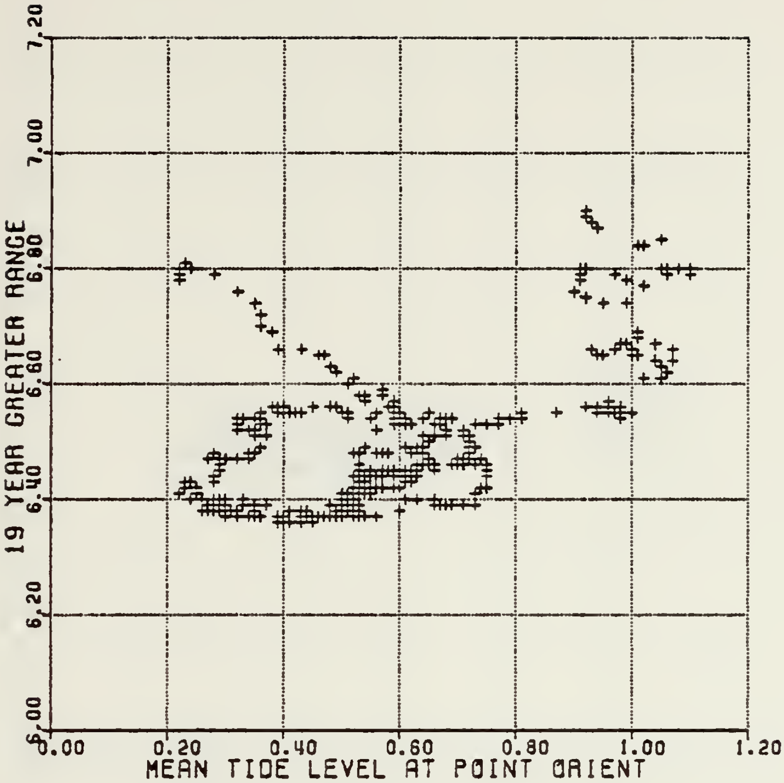
Graph 0-5



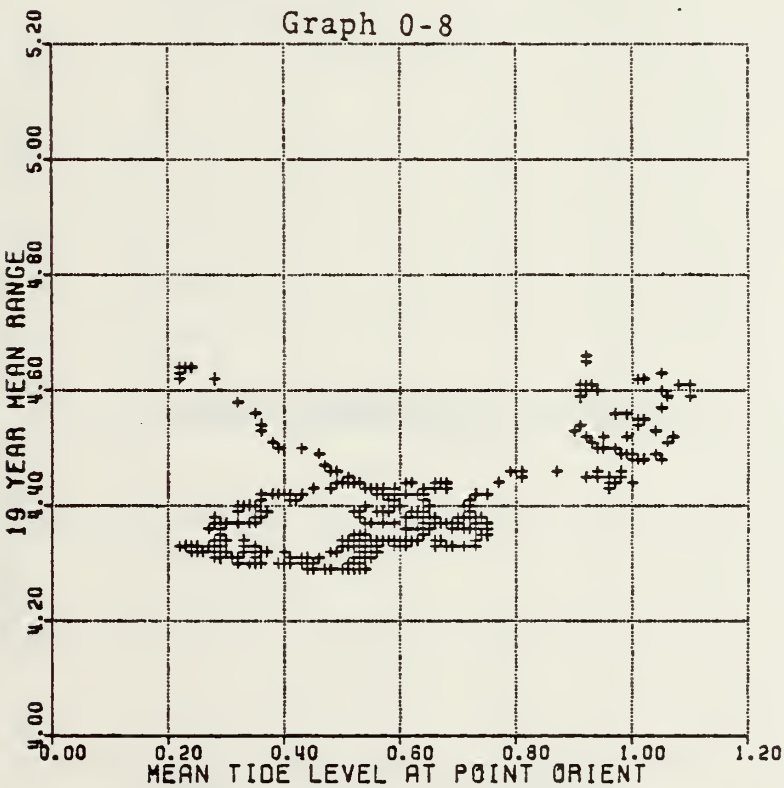
Graph 0-6



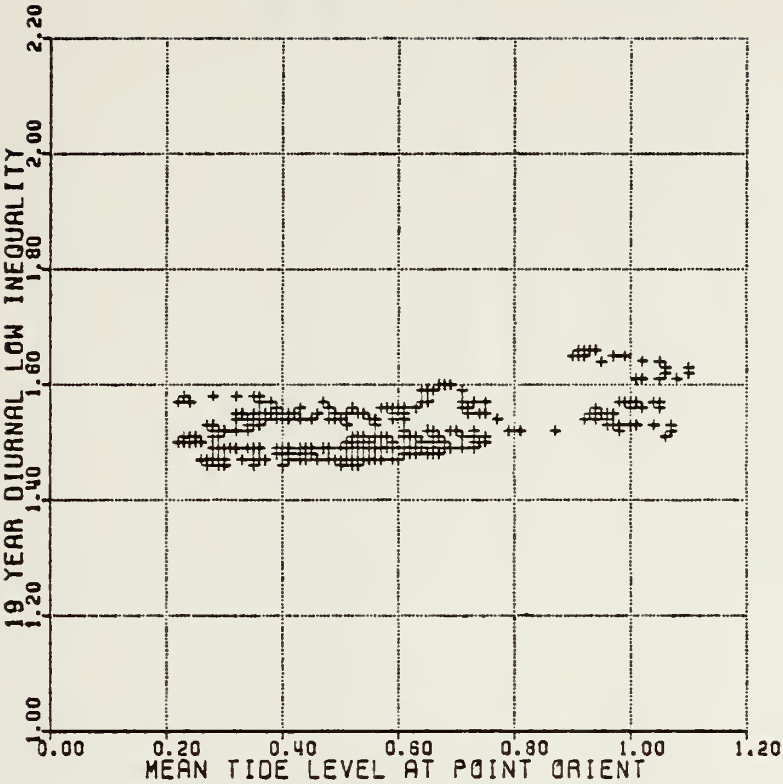
Graph 0-7



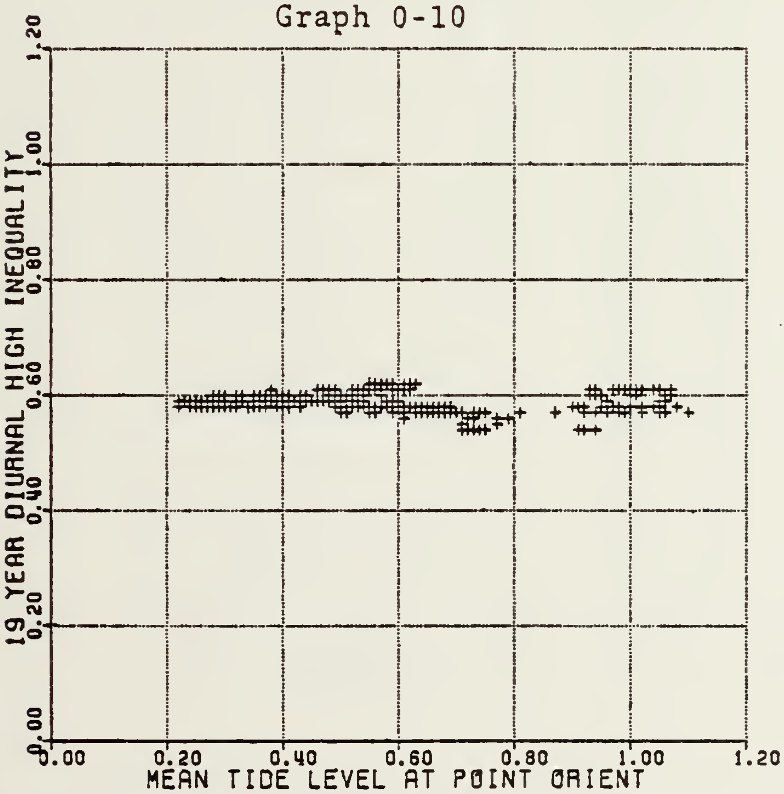
Graph 0-8



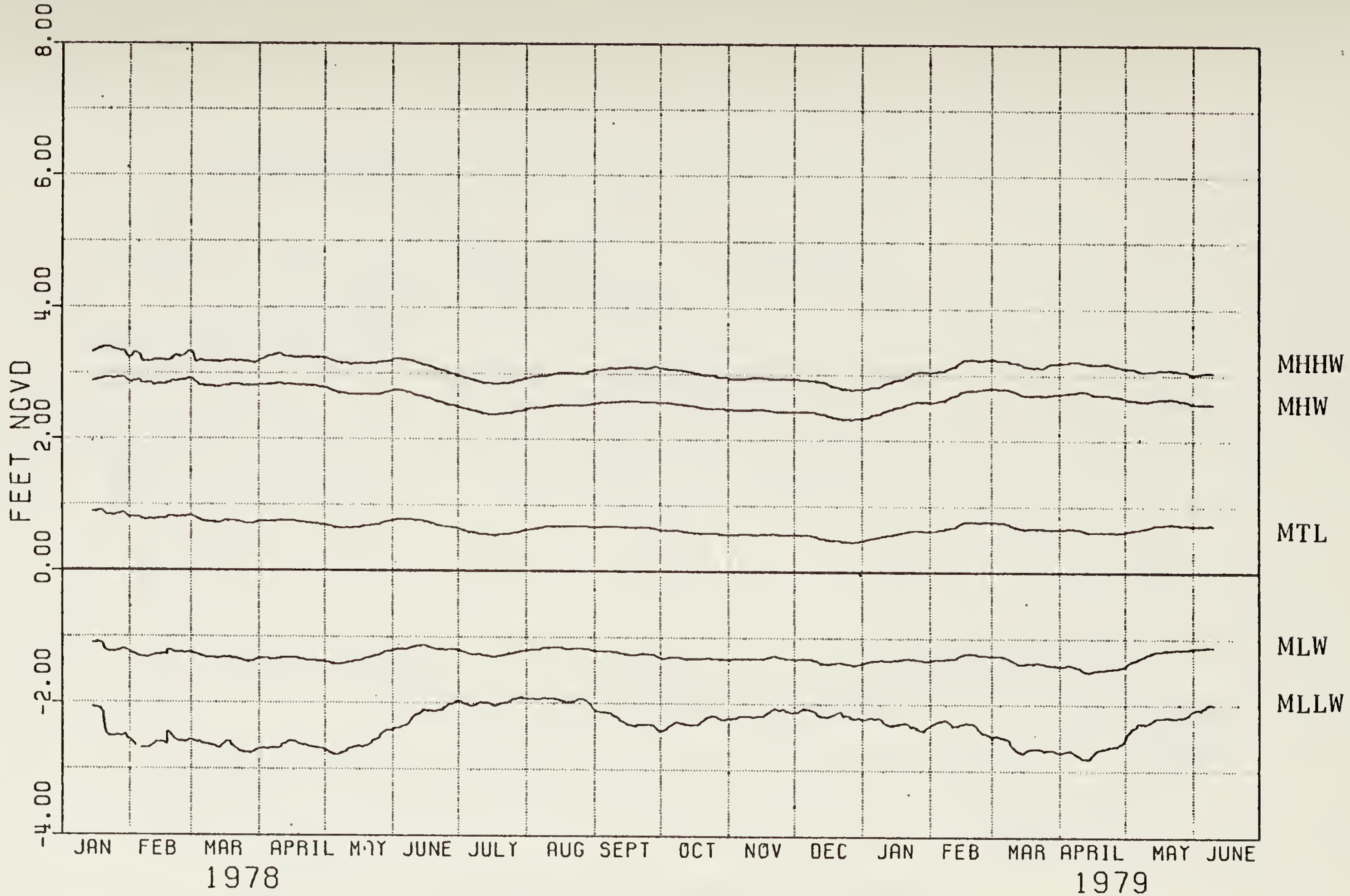
Graph 0-9



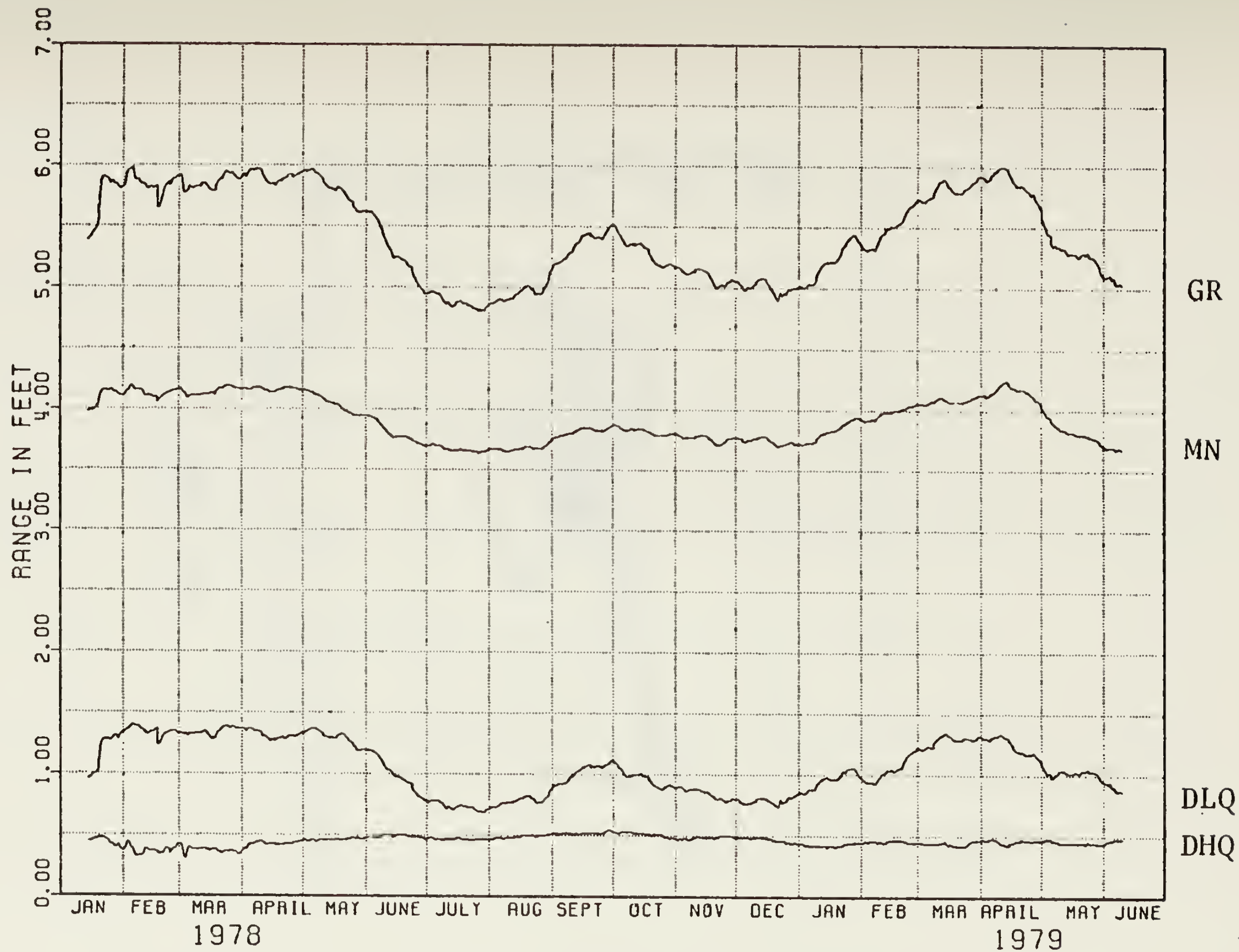
Graph 0-10



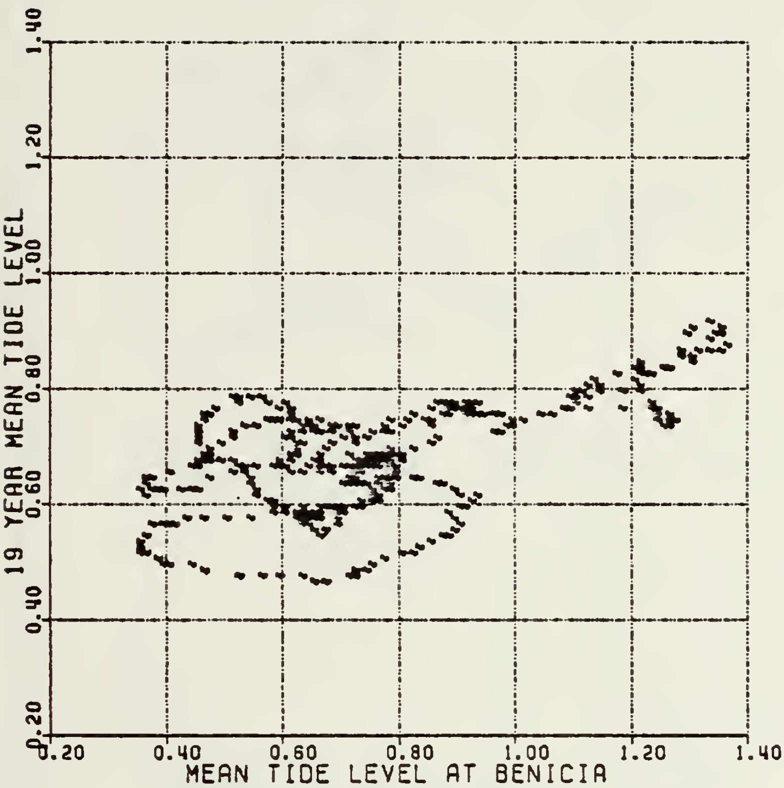
Graph 0-11



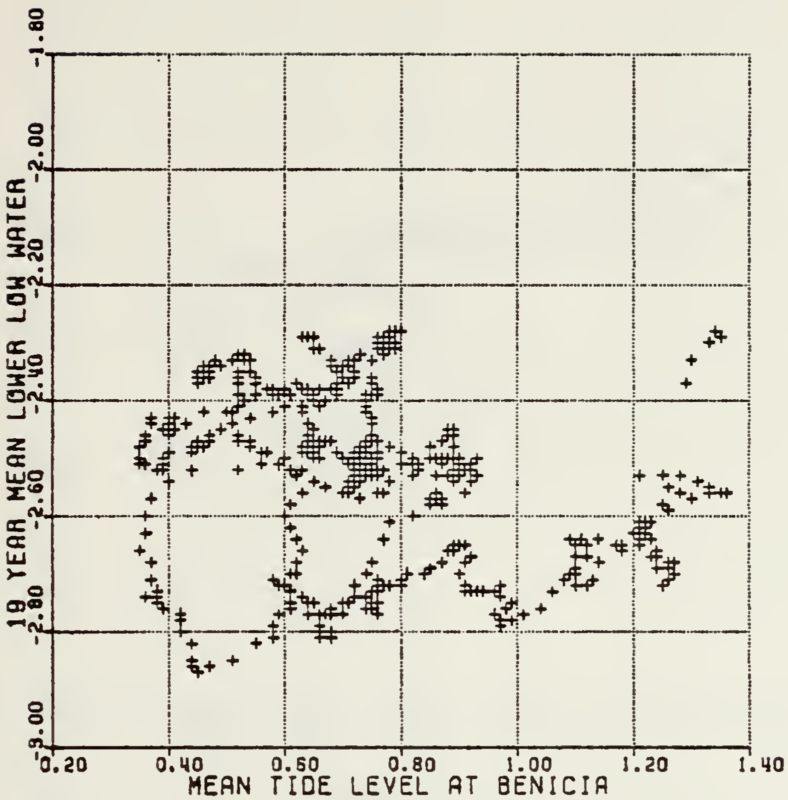
Graph B-1. 19-YEAR TIDAL DATUMS AT BENICIA.



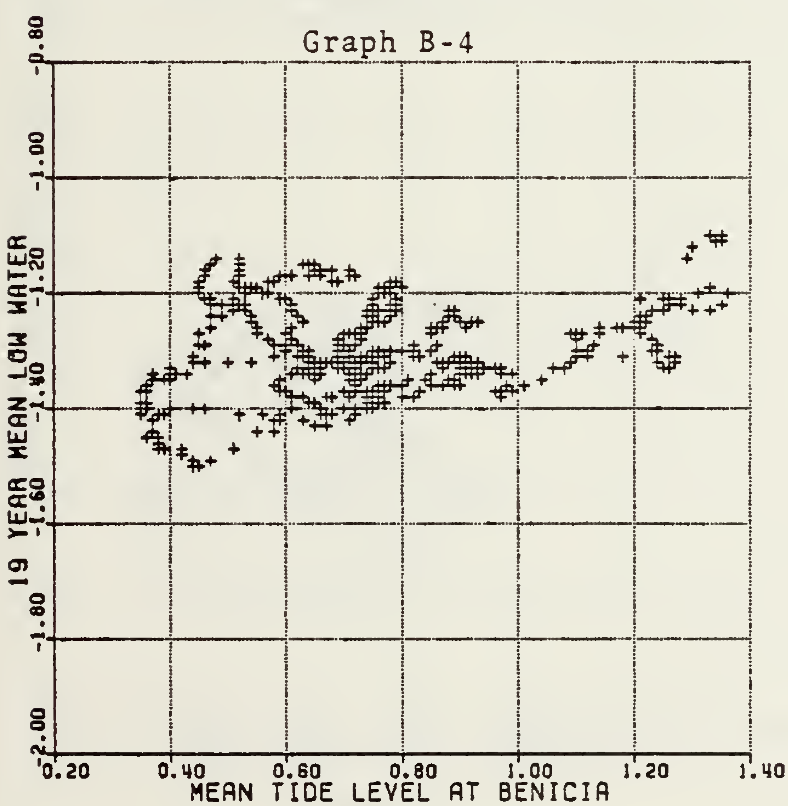
Graph B-2. 19-YEAR TIDAL RANGES AT BENICIA.


1.40
1.20
1.00
0.80
0.60
0.40
0.20
19 YEAR MEAN TIDE LEVEL
0.20
0.40
0.60
0.80
1.00
1.20
1.40
MEAN TIDE LEVEL AT BENICIA

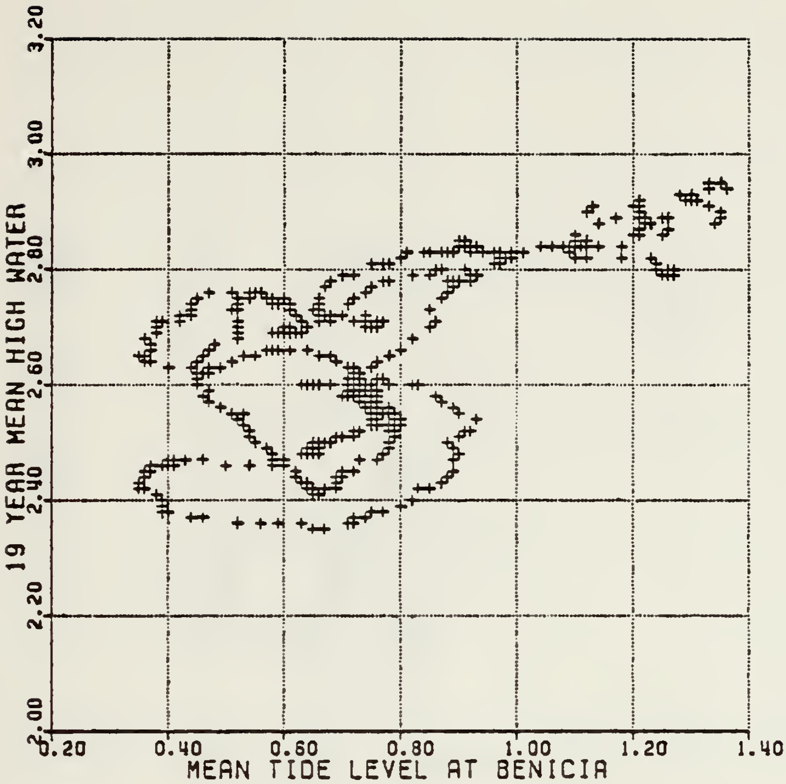
Graph B-3



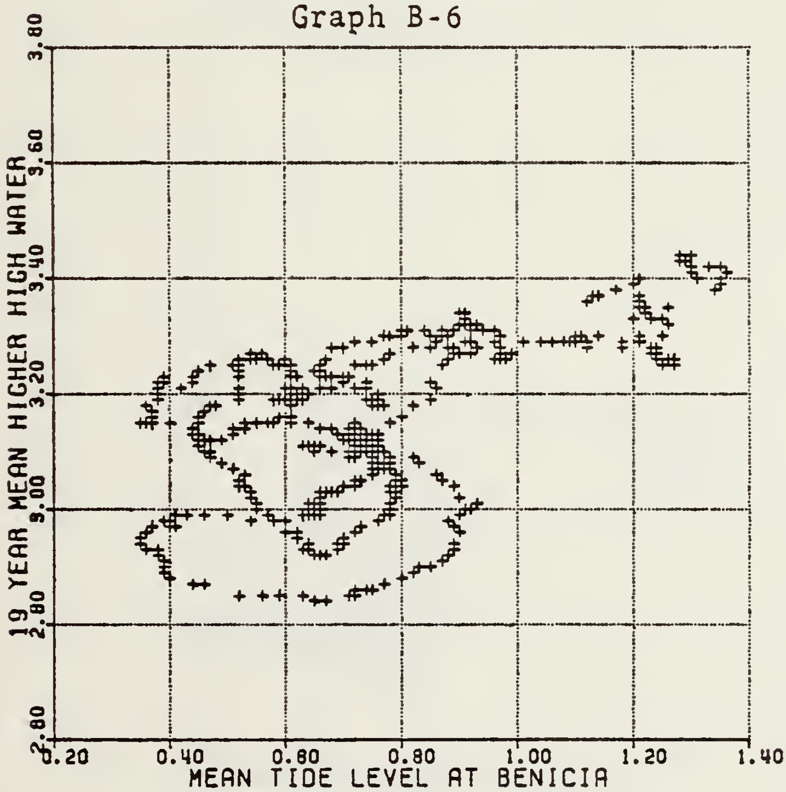
Graph B-4



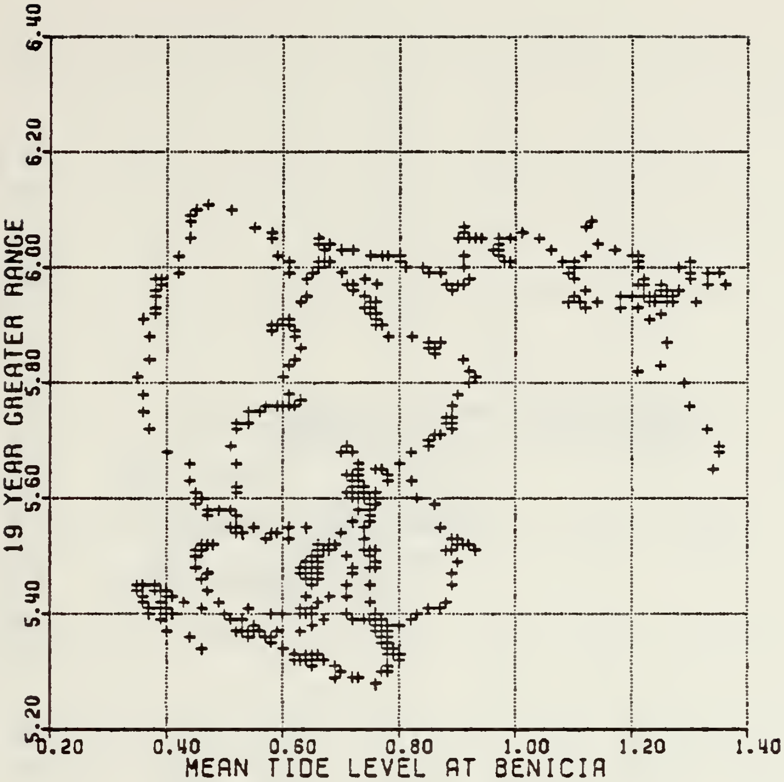
Graph B-5



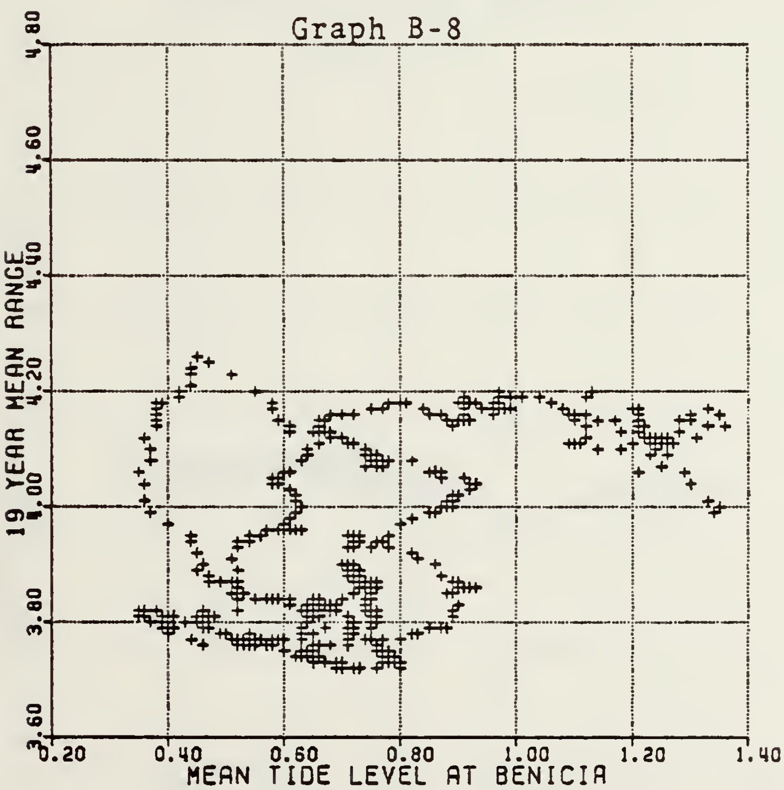
Graph B-6



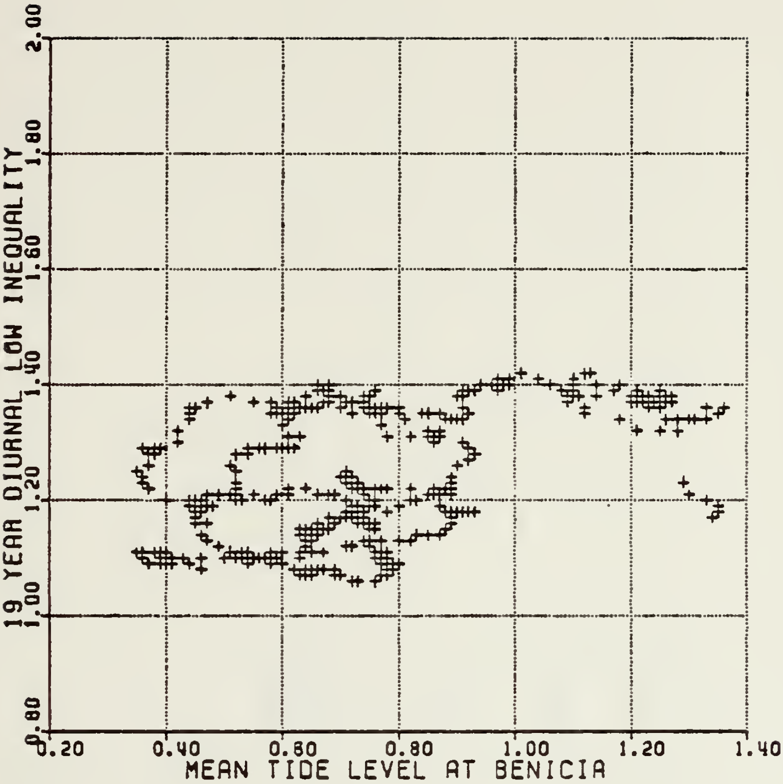
Graph B-7



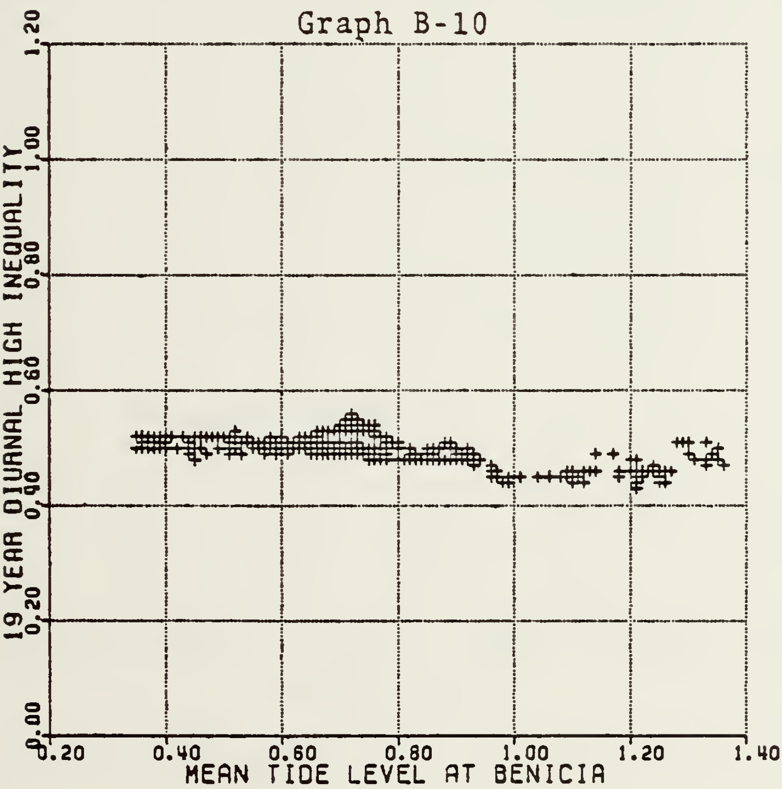
Graph B-8



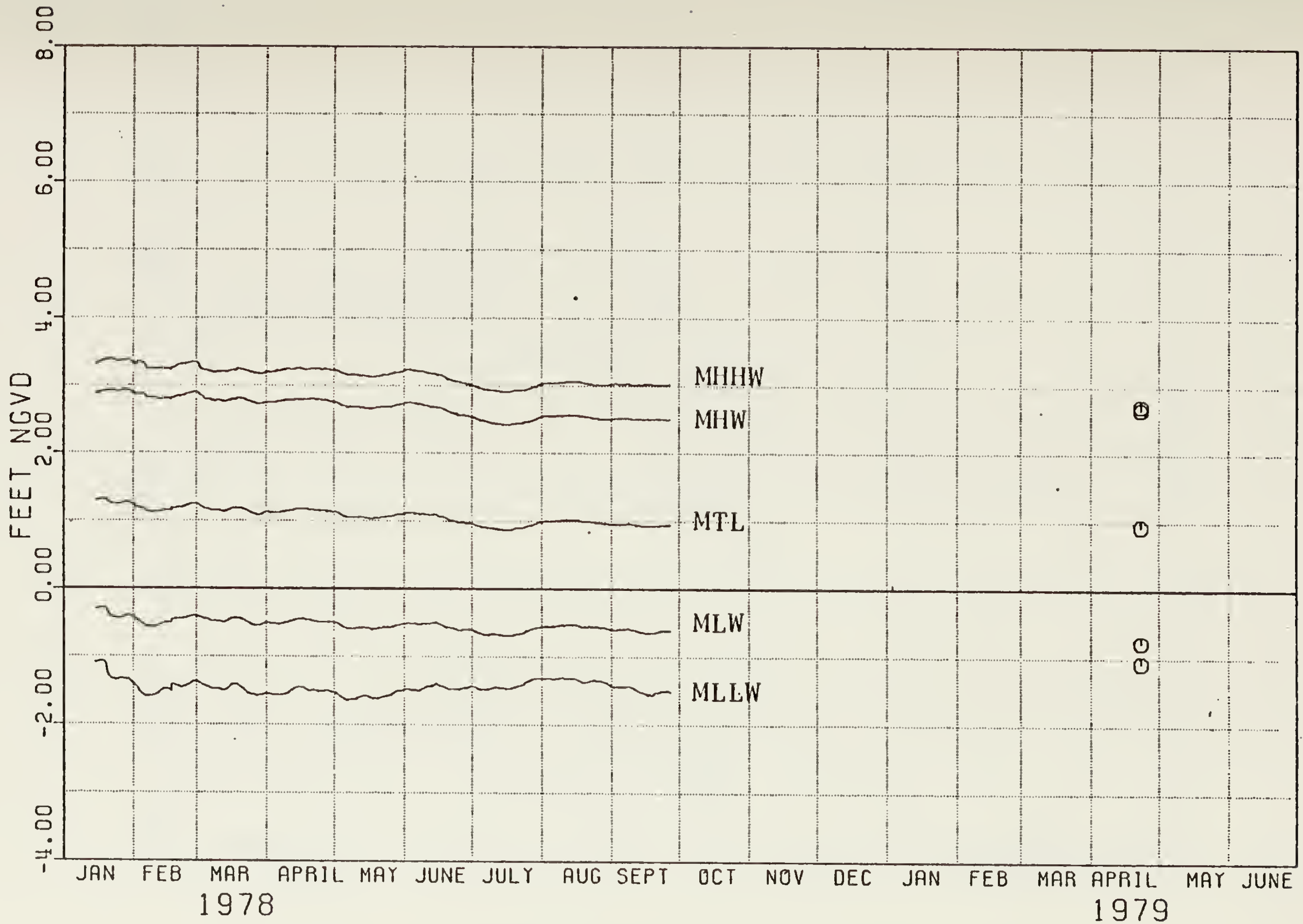
Graph B-9



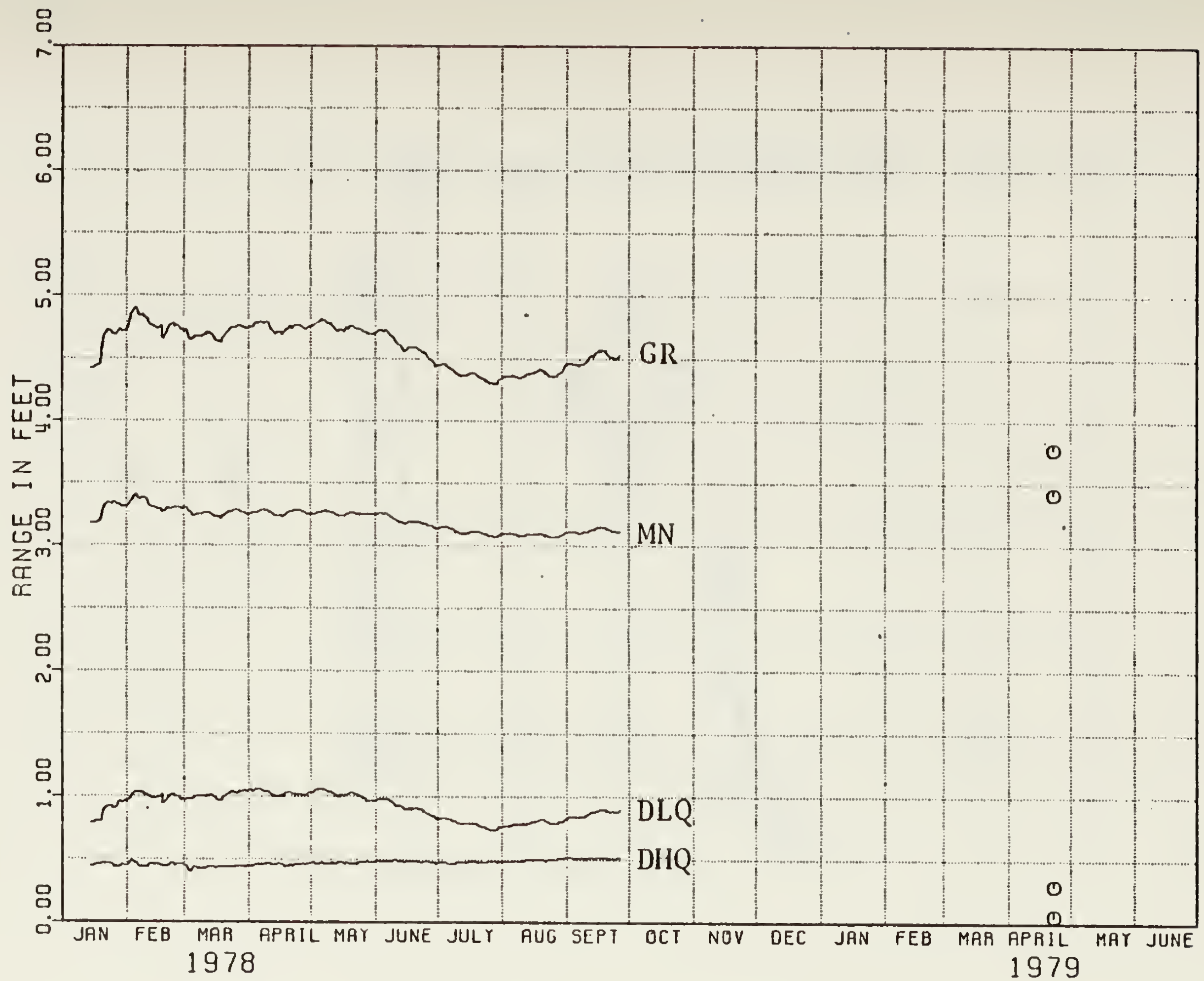
Graph B-10



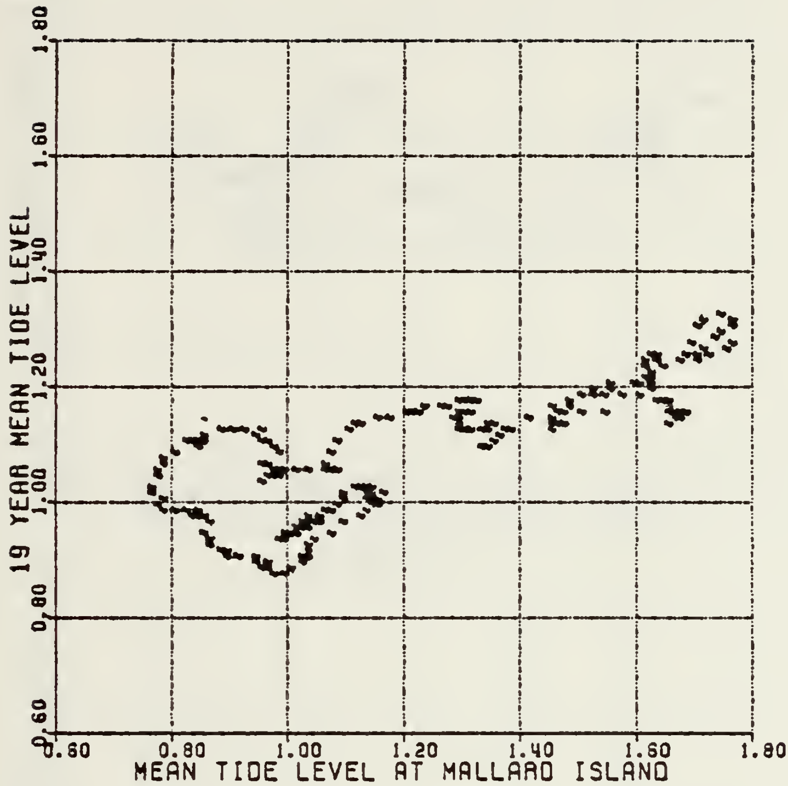
Graph B-11



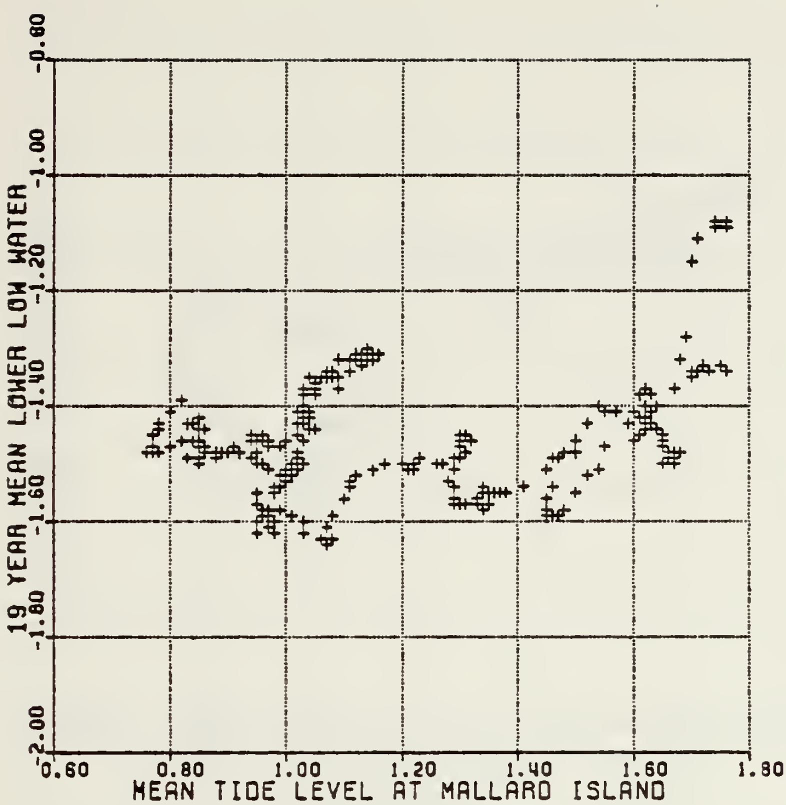
Graph M-1. 19-YEAR TIDAL DATUMS AT MALLARD ISLAND.



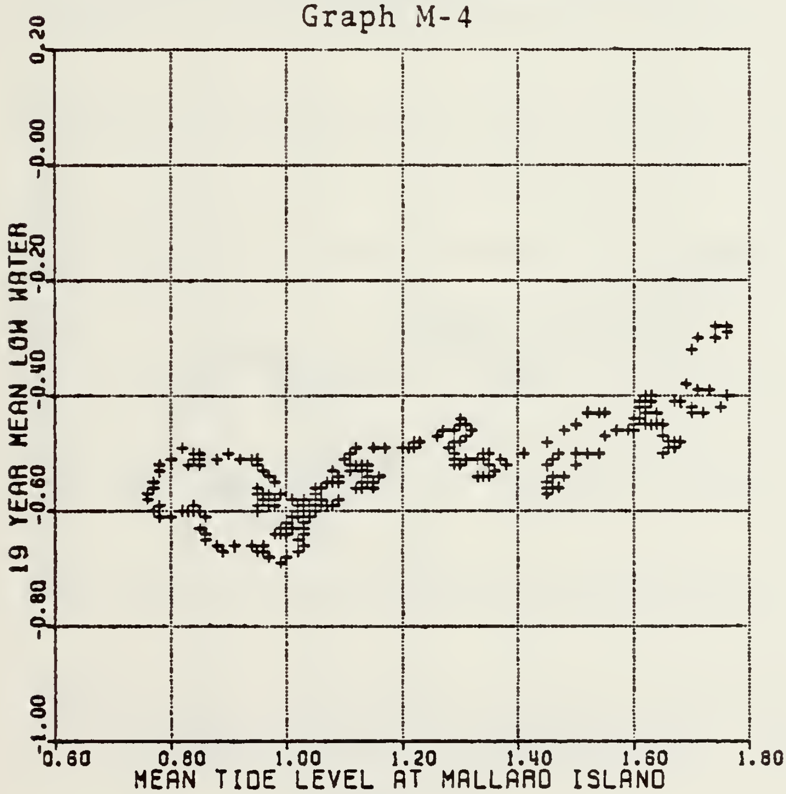
Graph M-2. 19-YEAR TIDAL RANGES AT MALLARD ISLAND.


19 YEAR MEAN TIDE LEVEL
0.60
0.80
1.00
1.20
1.40
1.60
1.80
0.60
0.80
1.00
1.20
1.40
1.60
1.80
MEAN TIDE LEVEL AT MALLARD ISLAND

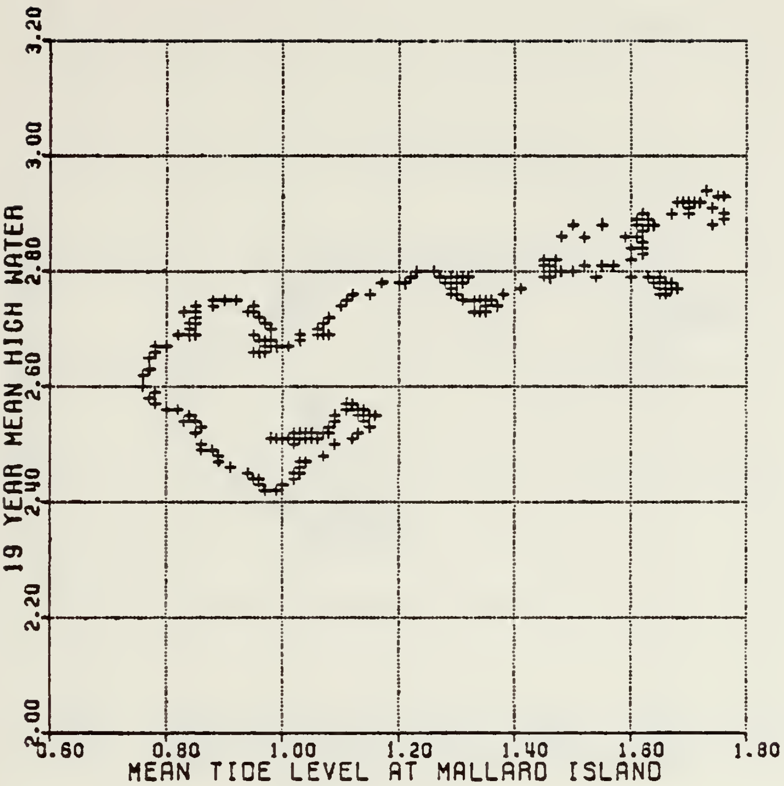
Graph M-3



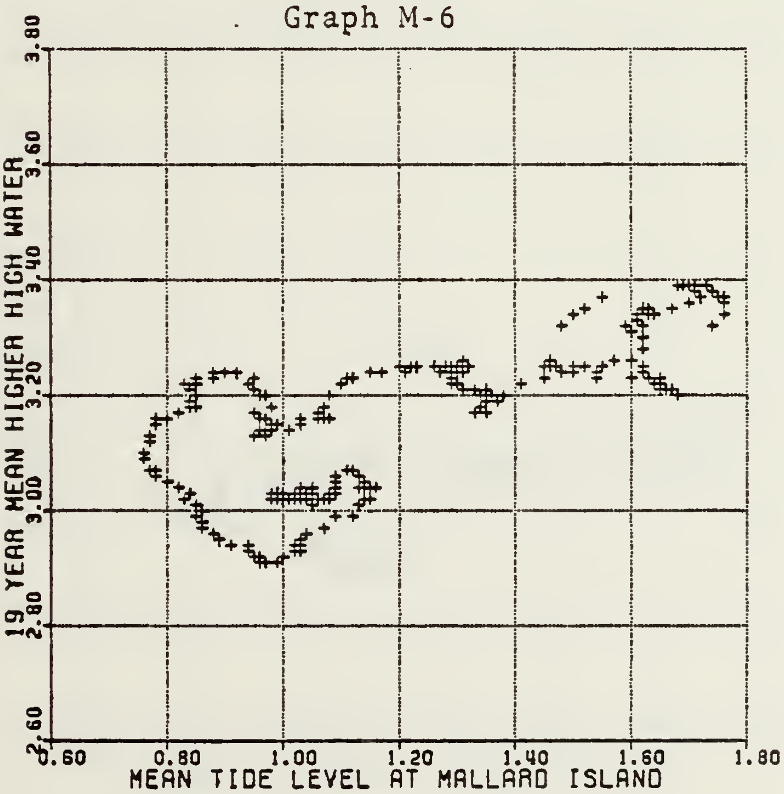
Graph M-4



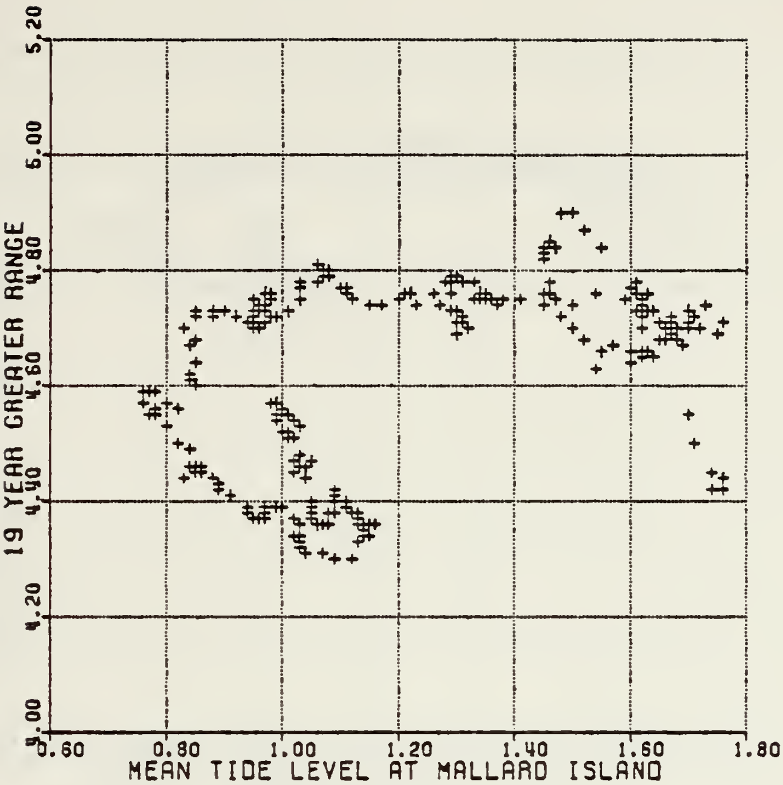
Graph M-5



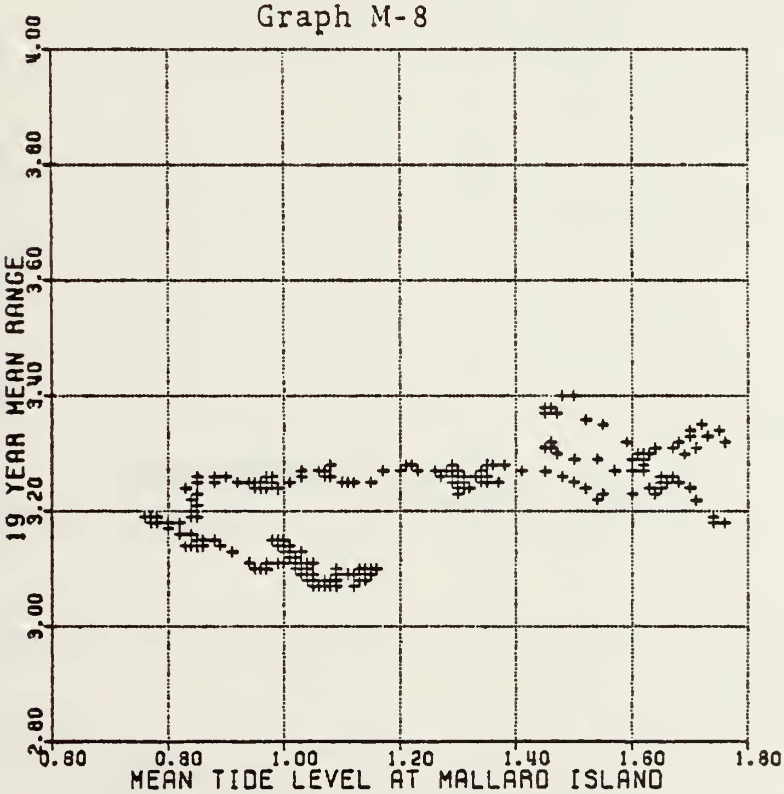
Graph M-6



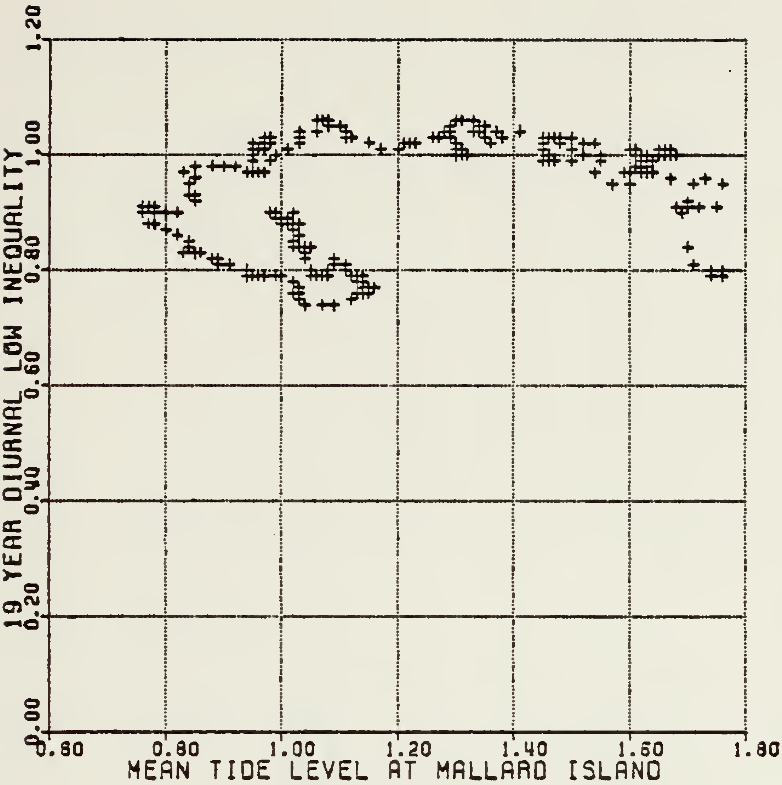
Graph M-7



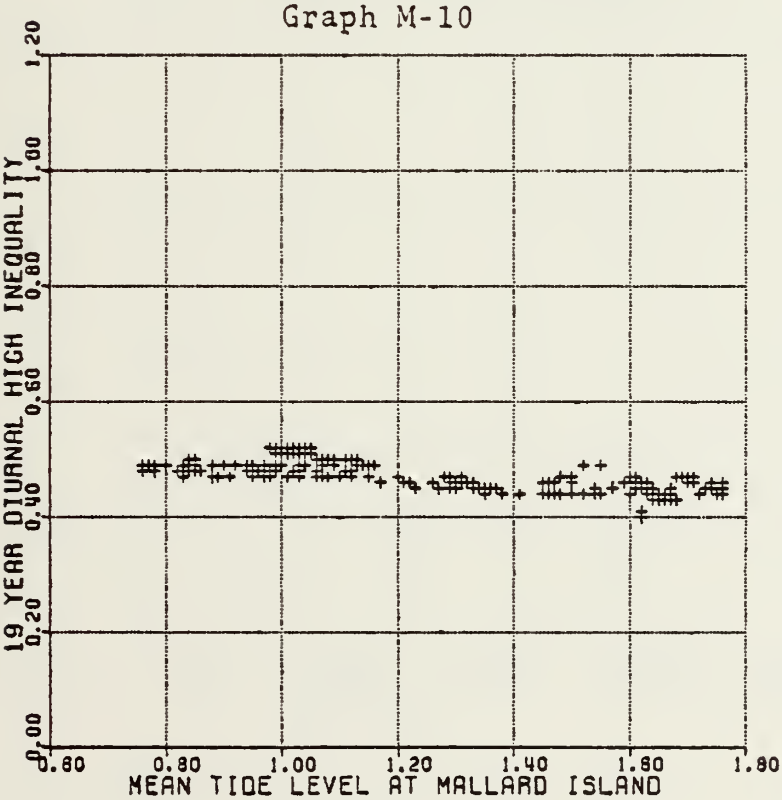
Graph M-8



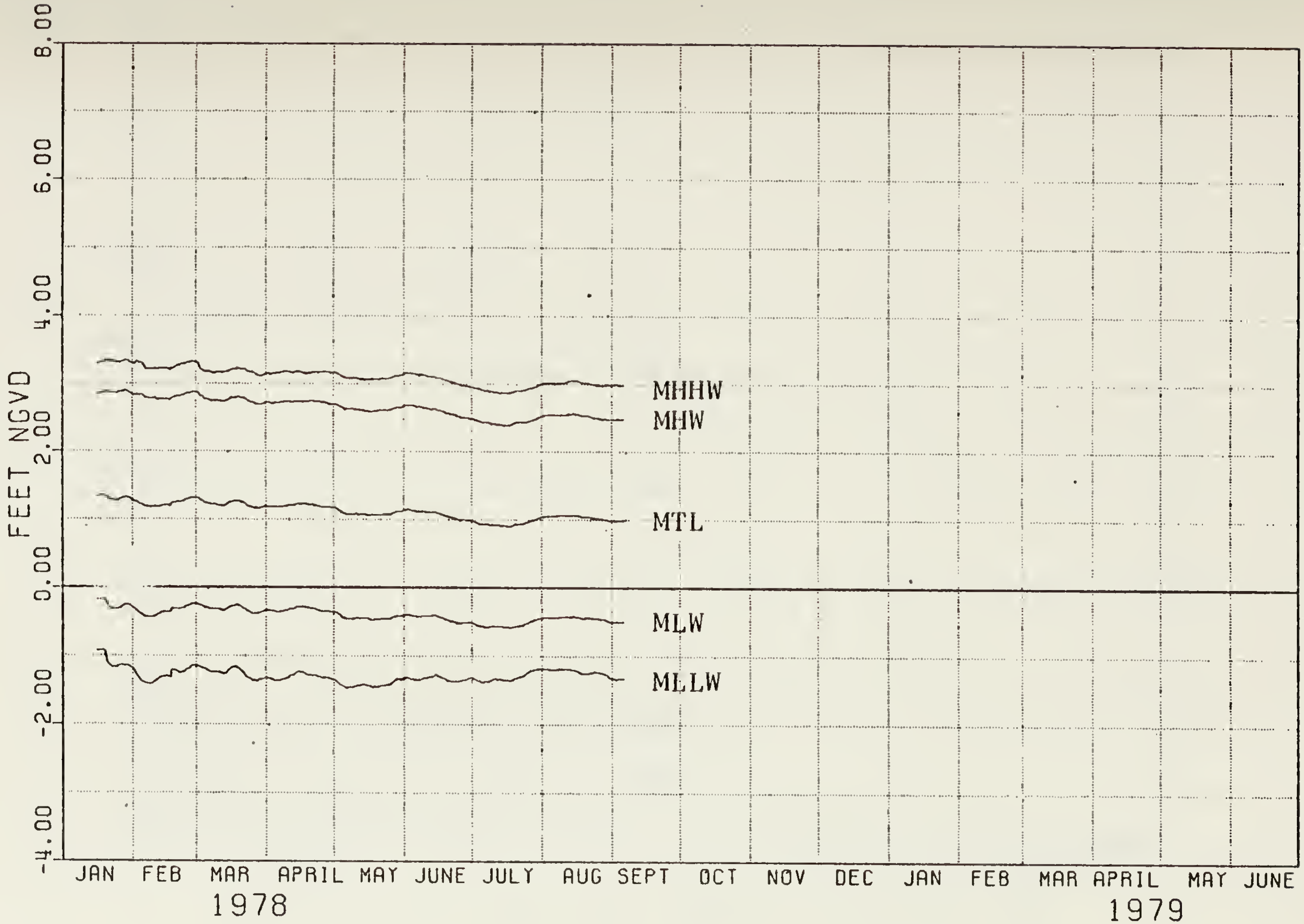
Graph M-9



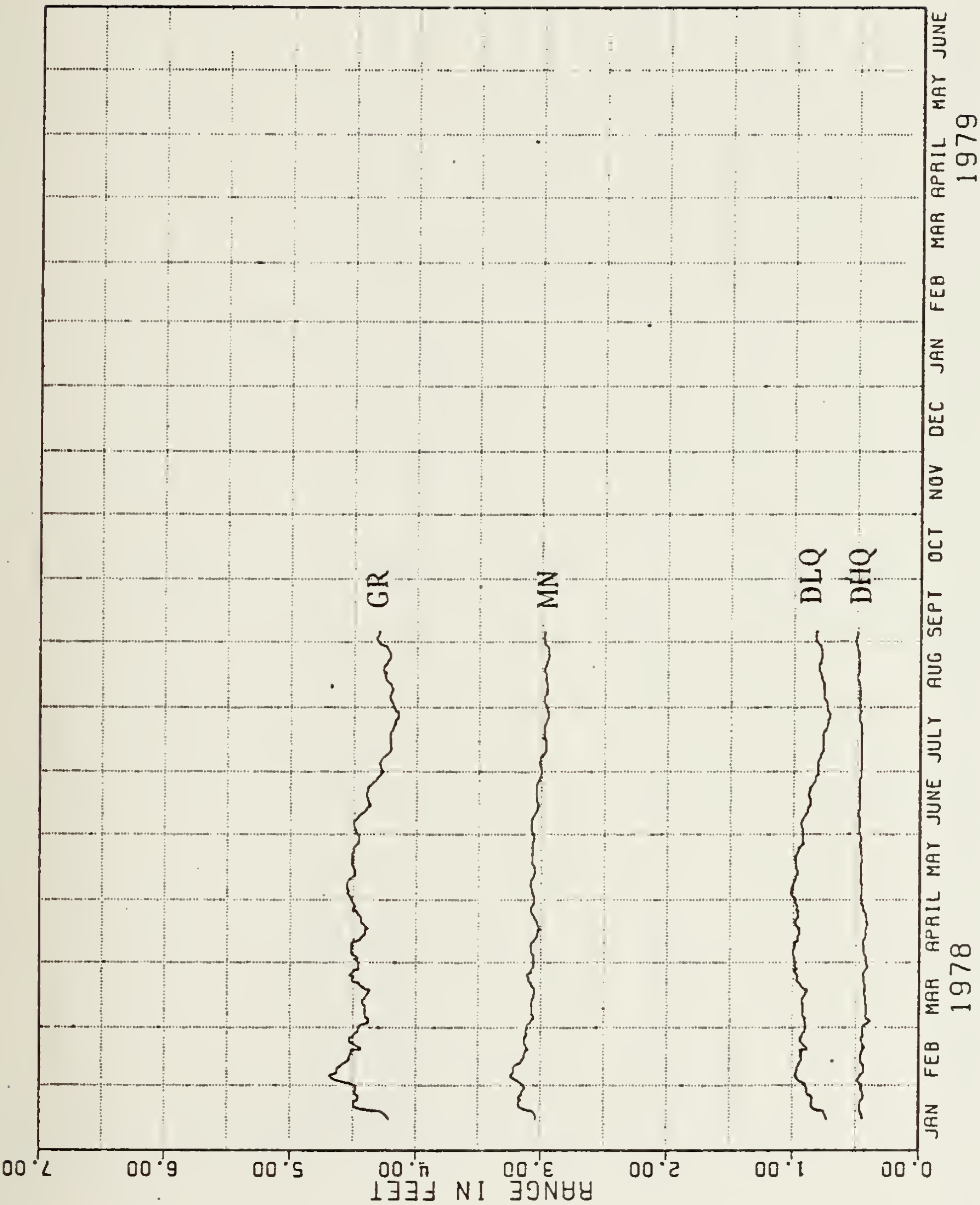
Graph M-10



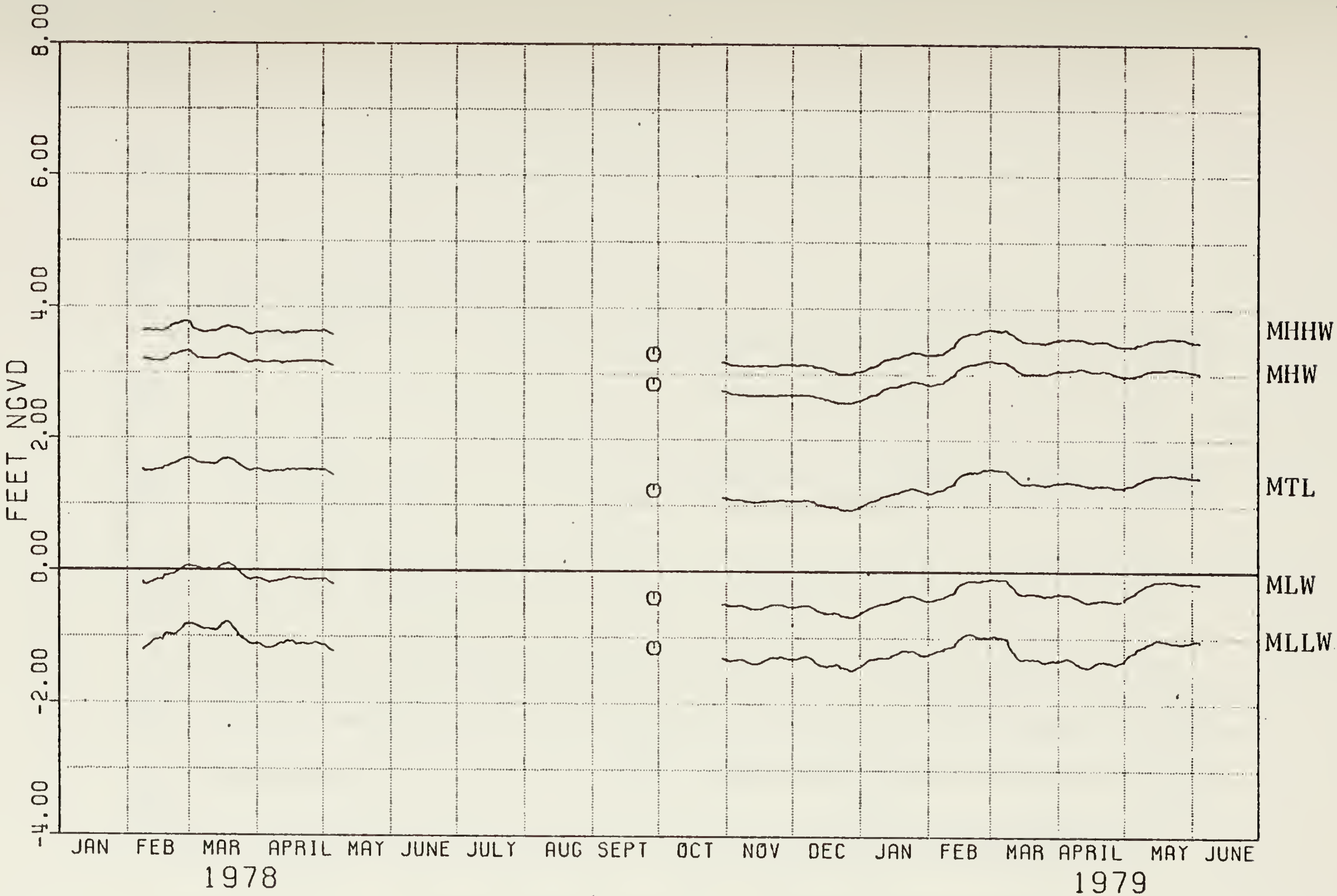
Graph M-11



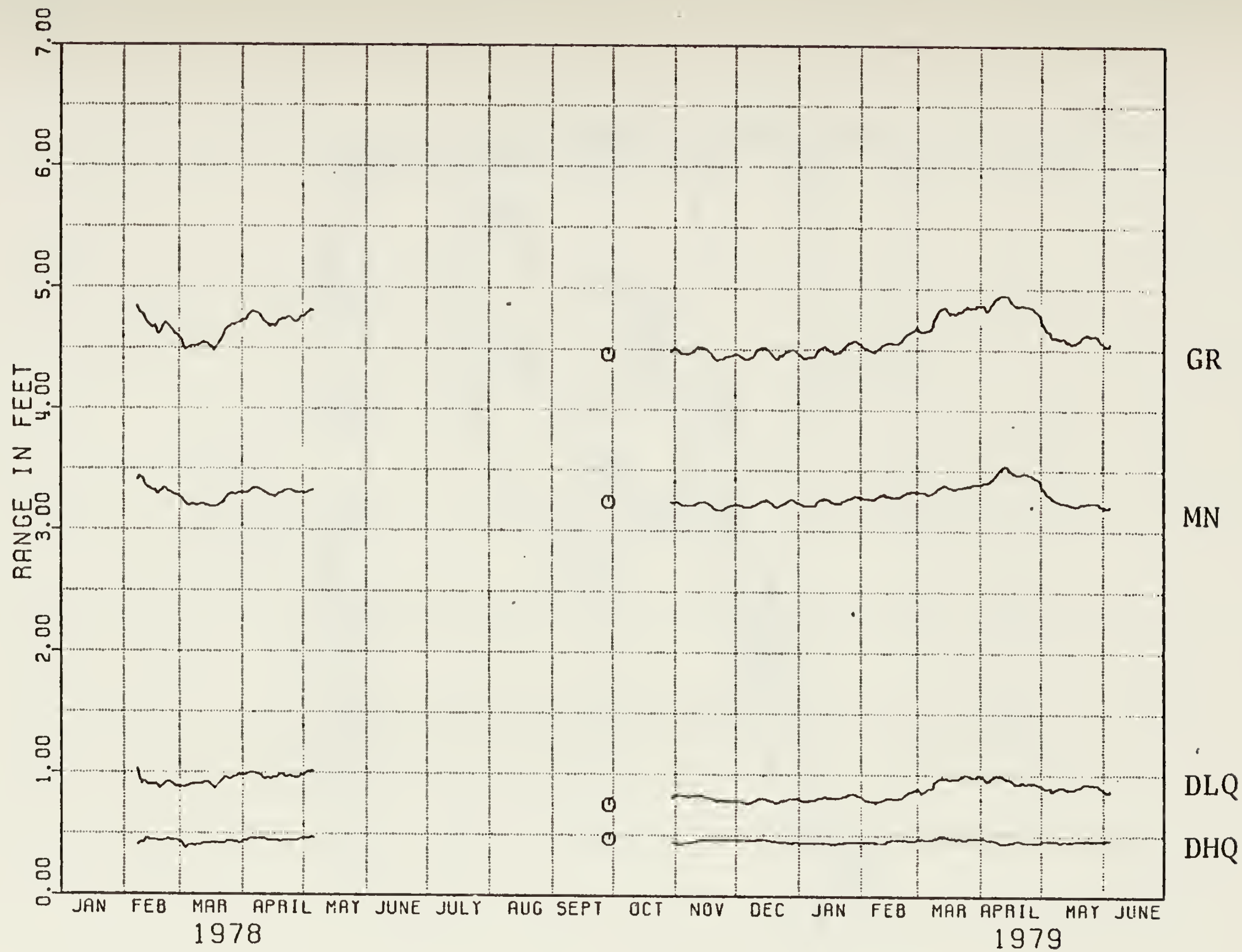
Graph C-1. 19-YEAR TIDAL DATUMS AT COLLINSVILLE.



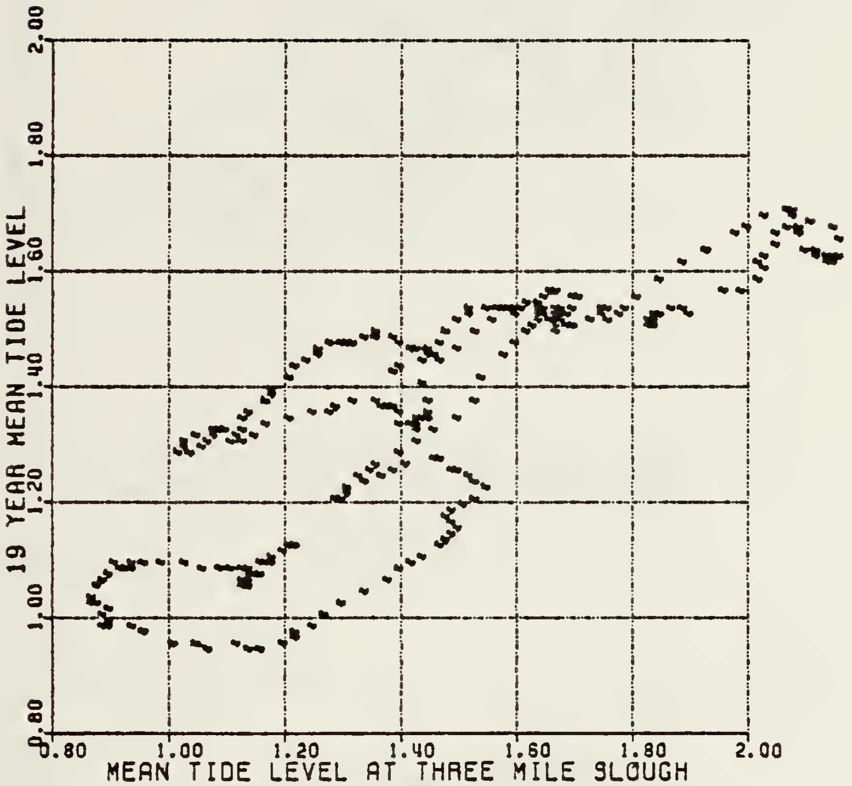
Graph C-2. 19-YEAR TIDAL RANGES AT COLLINSVILLE.



Graph T-1. 19-YEAR TIDAL DATUMS AT THREE MILE SLOUGH.

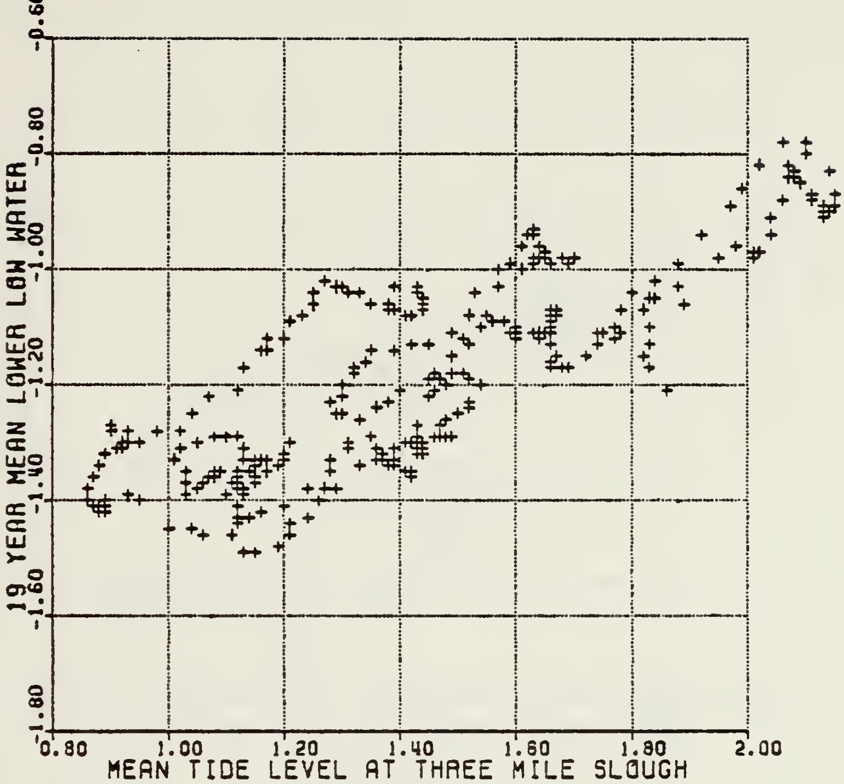


Graph T-2. 19-YEAR TIDAL RANGES AT THREE MILE SLOUGH.

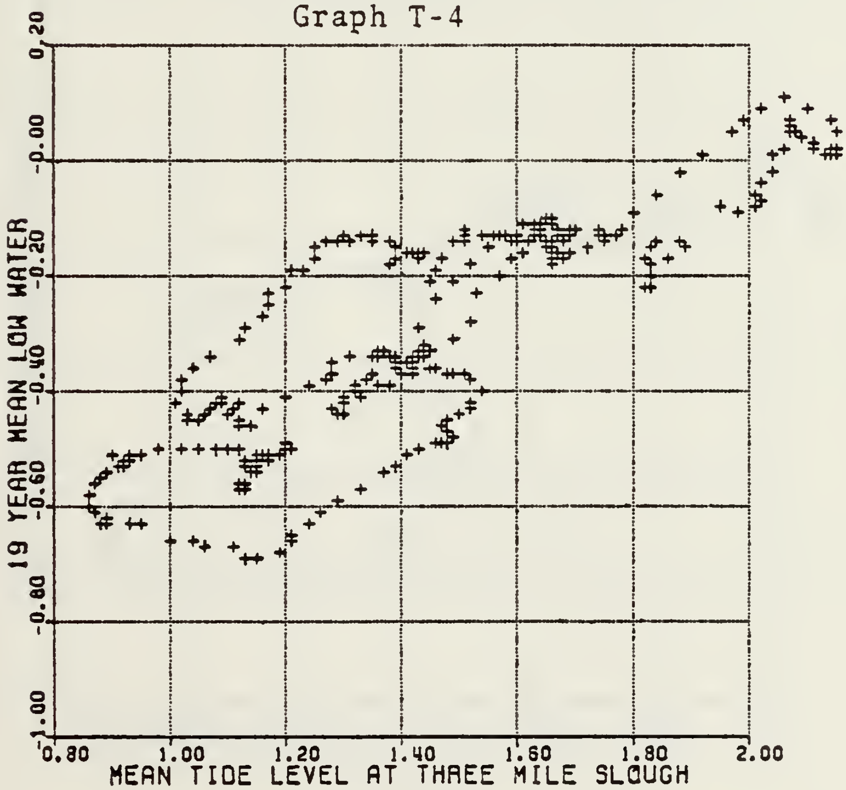


19 YEAR MEAN TIDE LEVEL
0.80
1.00
1.20
1.40
1.60
1.80
2.00
MEAN TIDE LEVEL AT THREE MILE SLOUGH

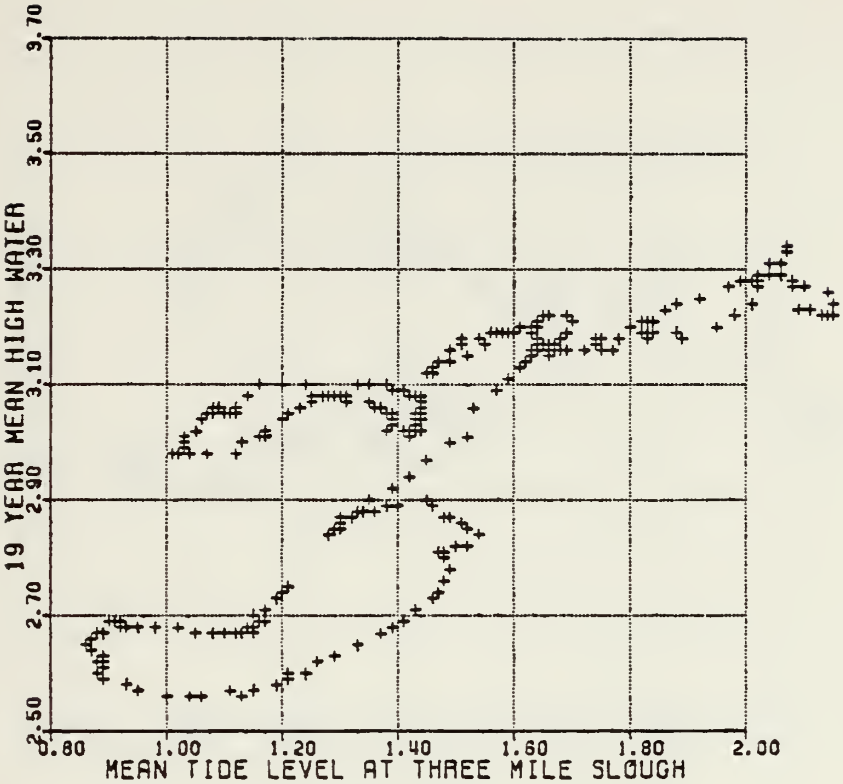
Graph T-3



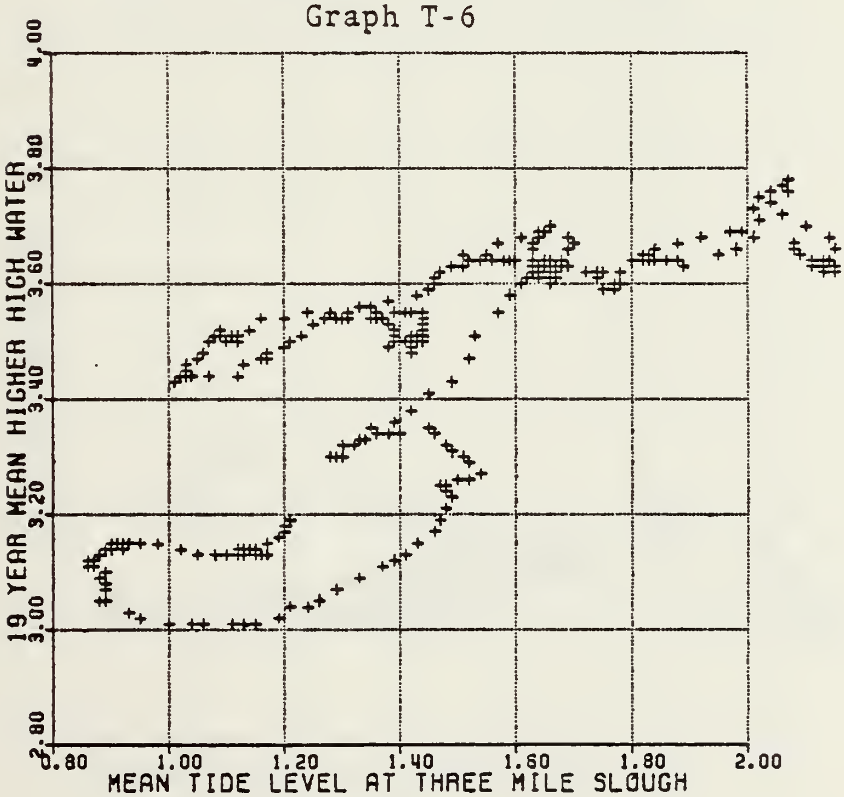
Graph T-4



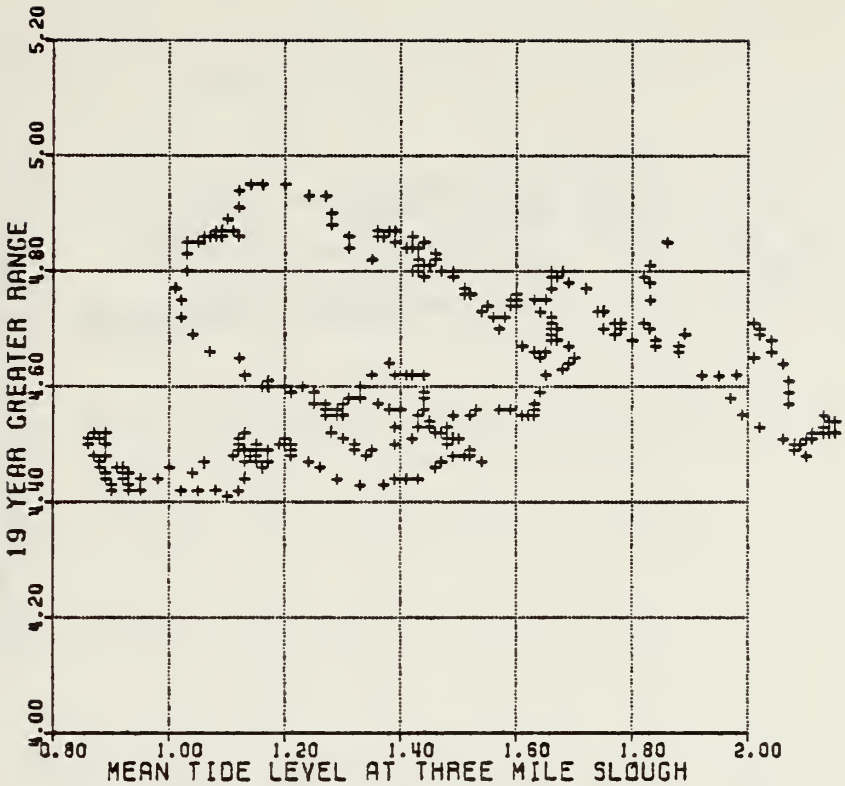
Graph T-5



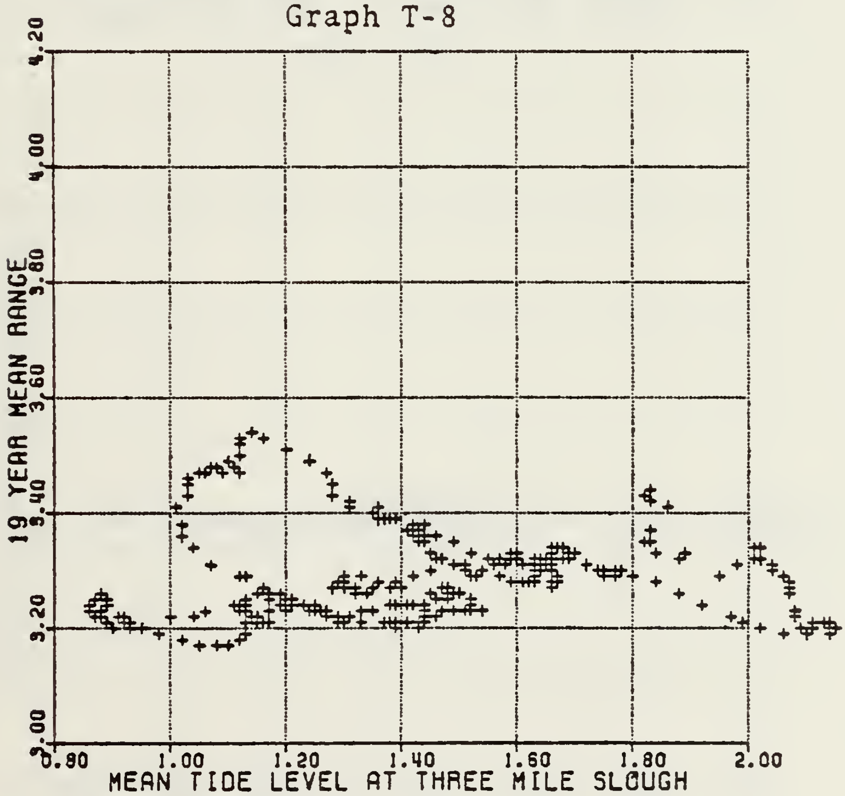
Graph T-6



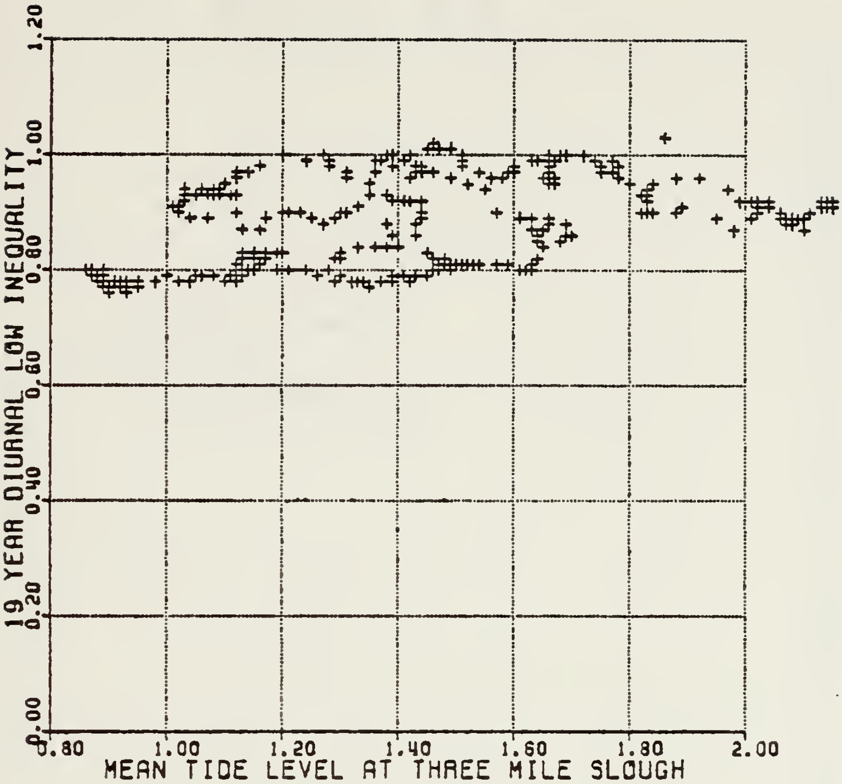
Graph T-7



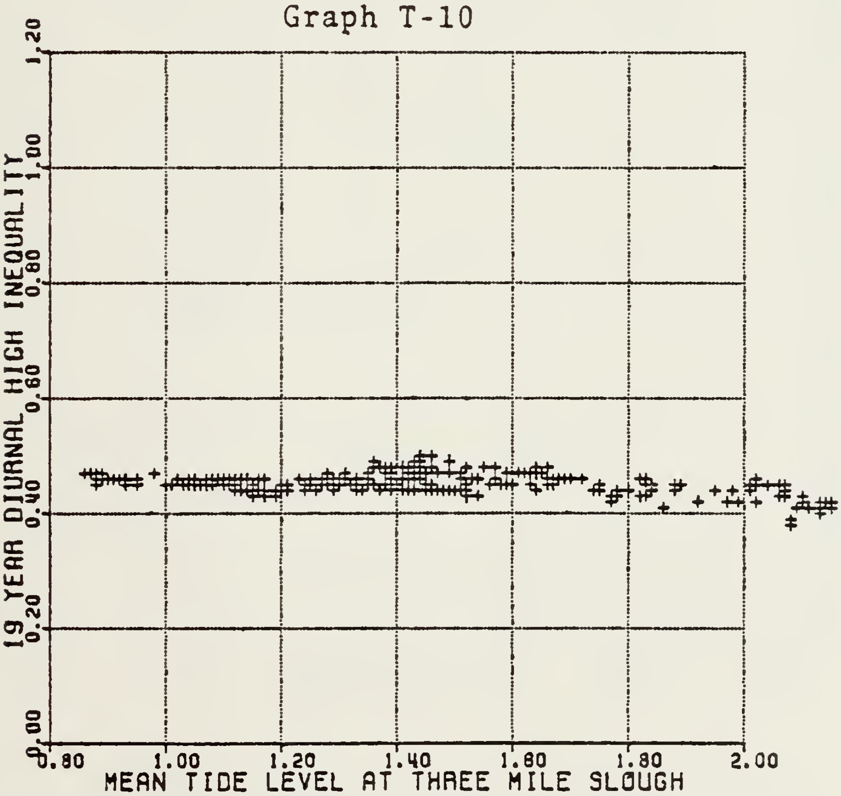
Graph T-8



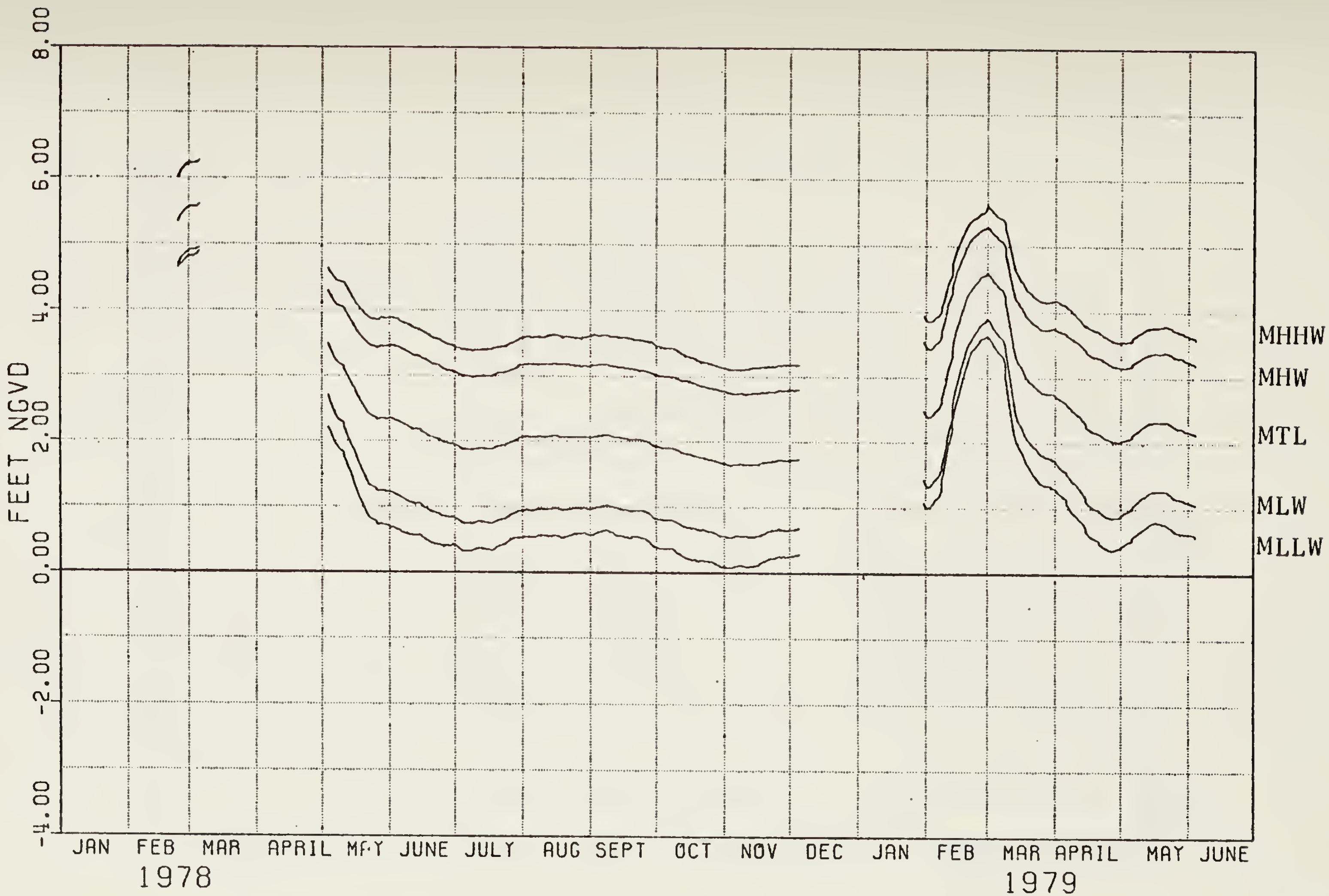
Graph T-9



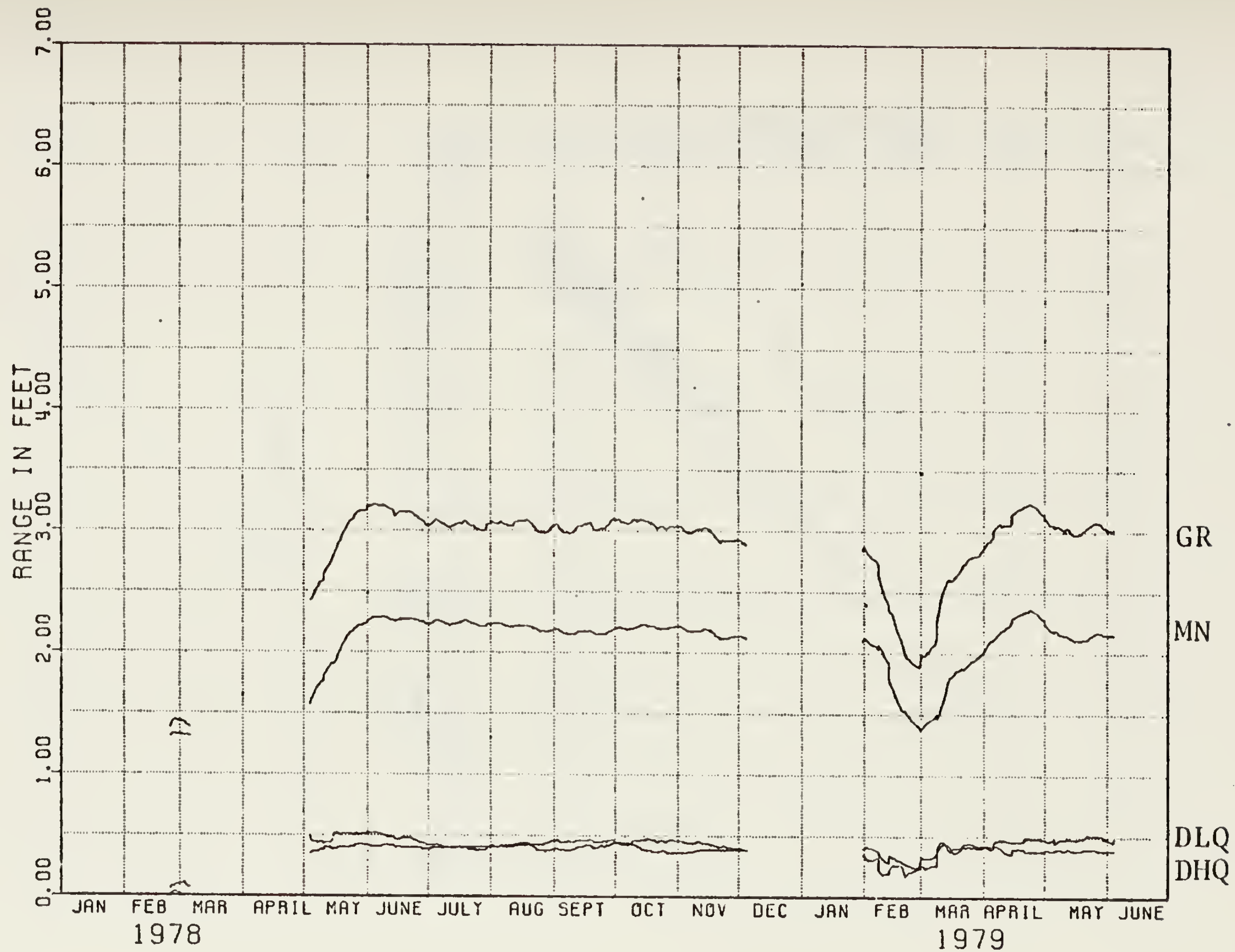
Graph T-10



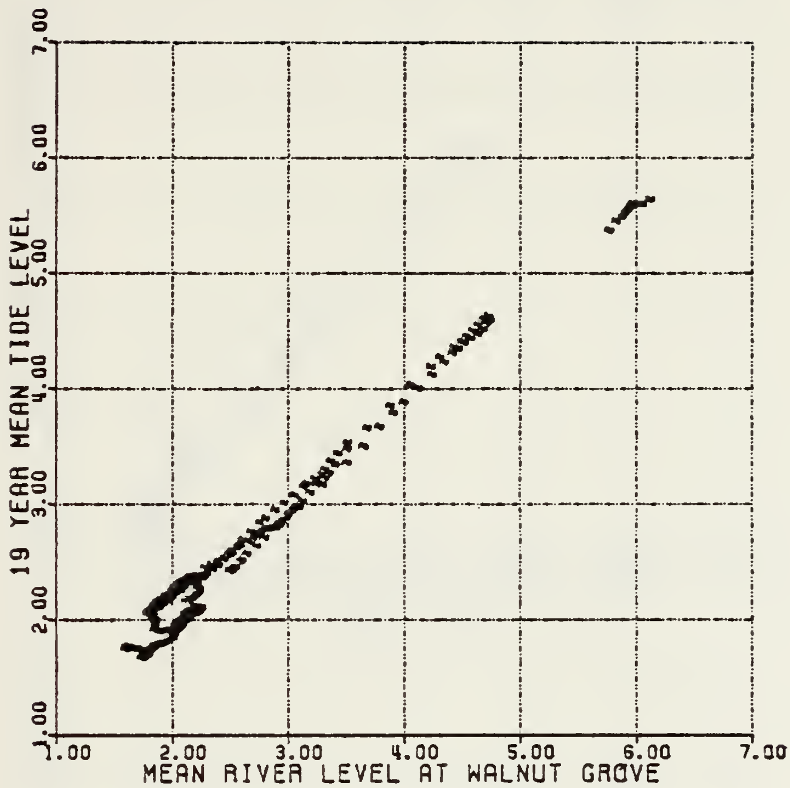
Graph T-11



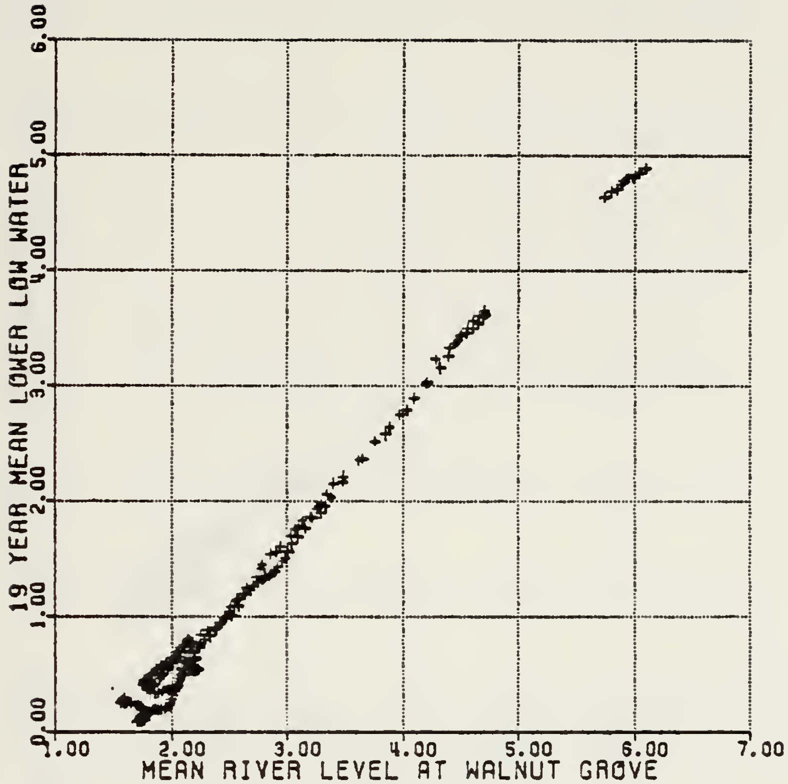
Graph W-1. 19-YEAR TIDAL DATUMS AT WALNUT GROVE.



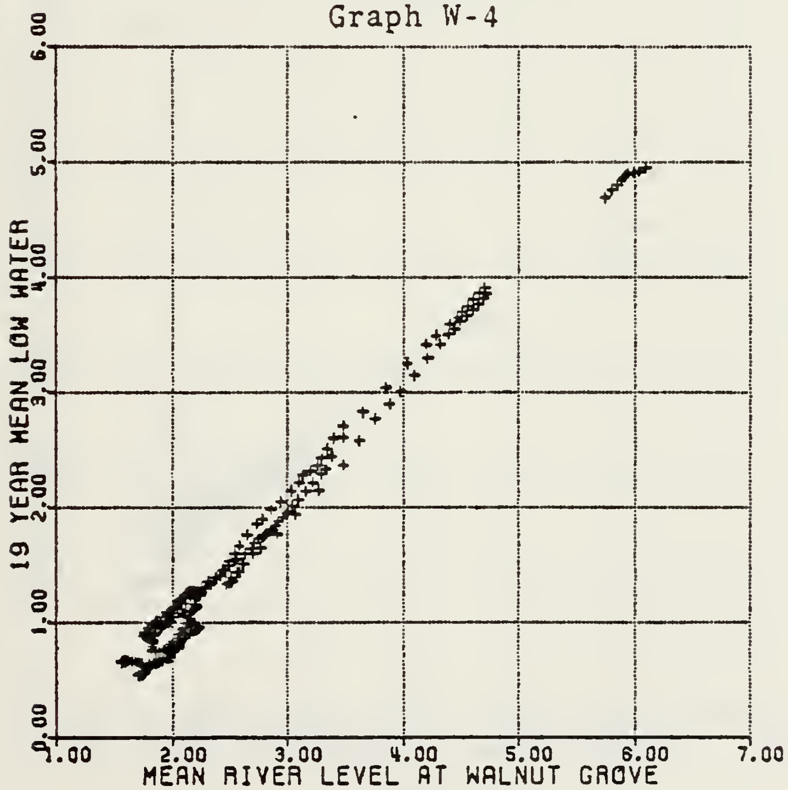
Graph W-2. 19-YEAR TIDAL RANGES AT WALNUT GROVE.


7.00
6.00
5.00
4.00
3.00
2.00
1.00
19 YEAR MEAN TIDE LEVEL
1.00
2.00
3.00
4.00
5.00
6.00
7.00
MEAN RIVER LEVEL AT WALNUT GROVE

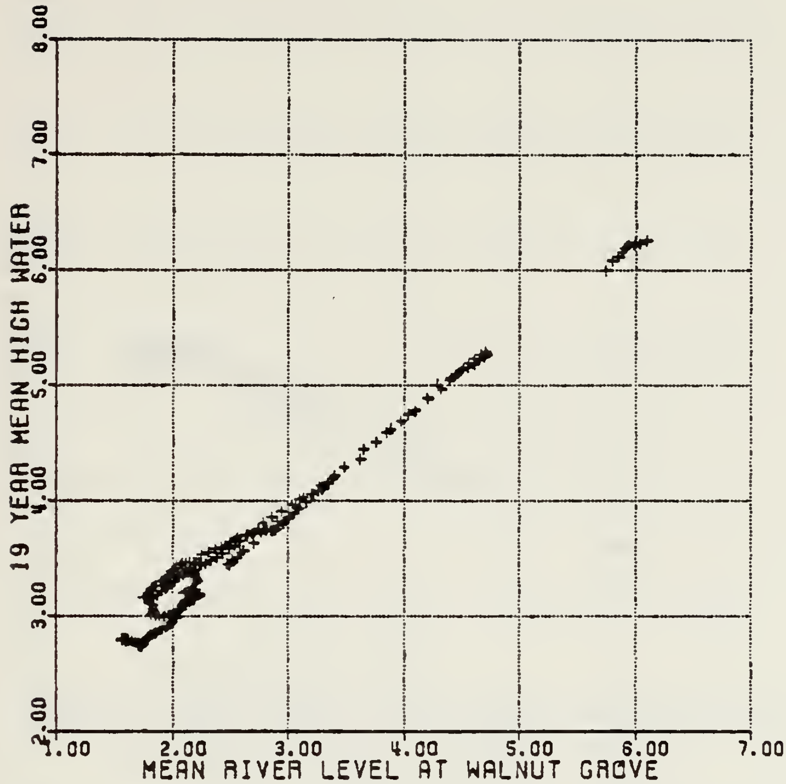
Graph W-3



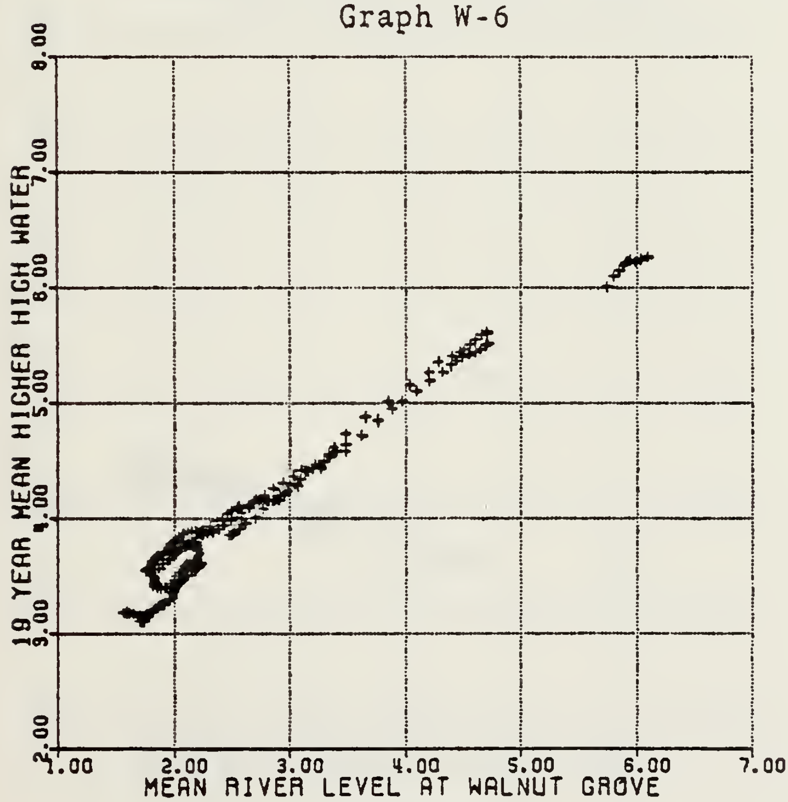
Graph W-4



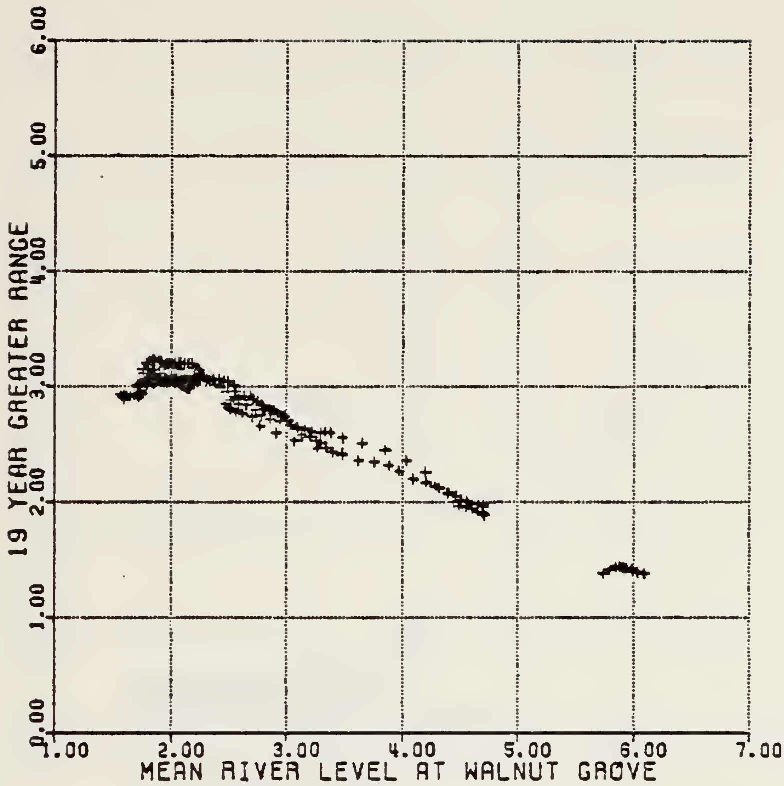
Graph W-5



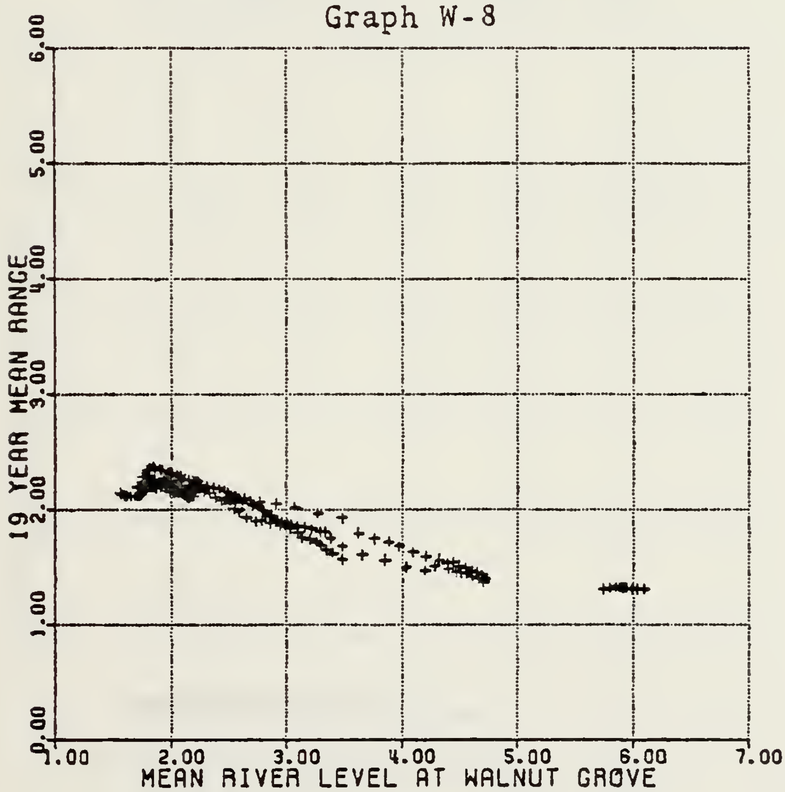
Graph W-6



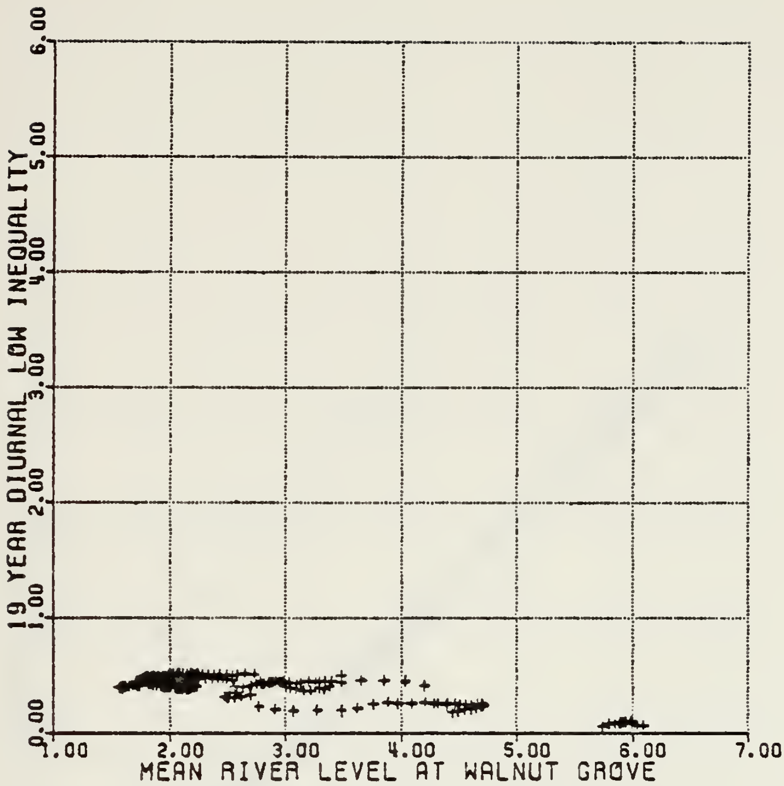
Graph W-7



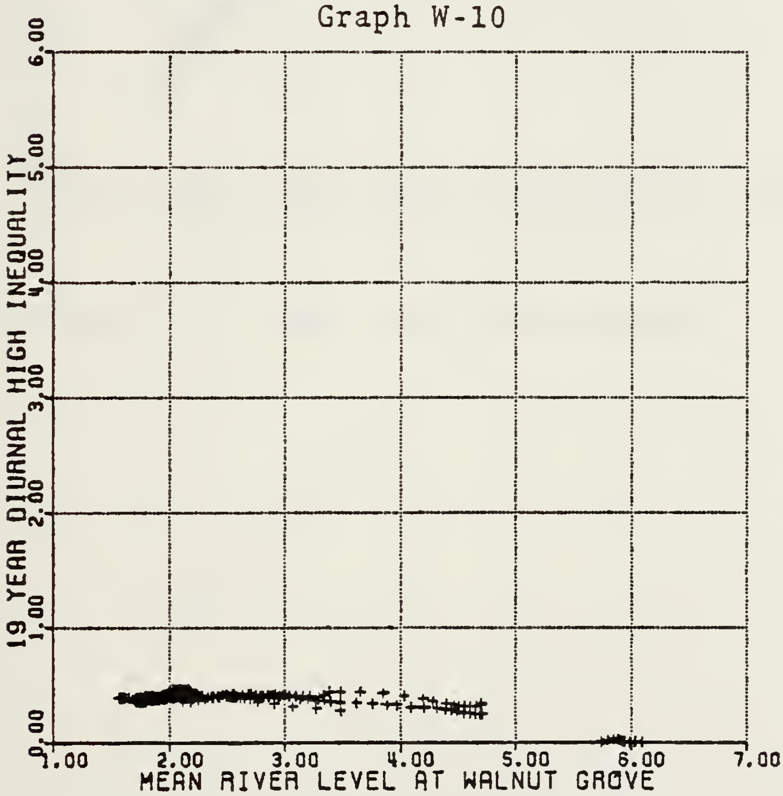
Graph W-8



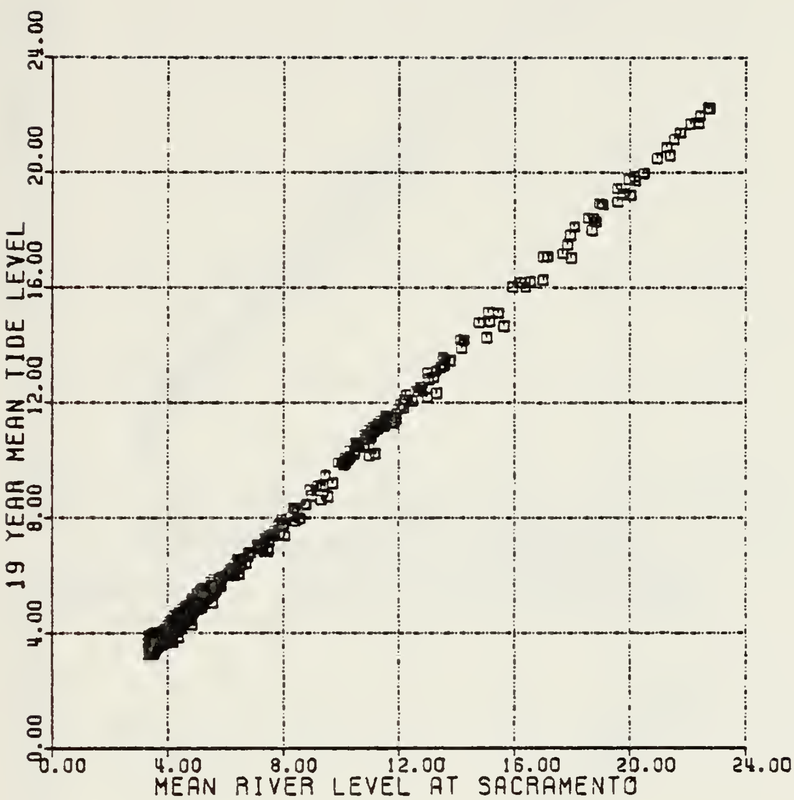
Graph W-9



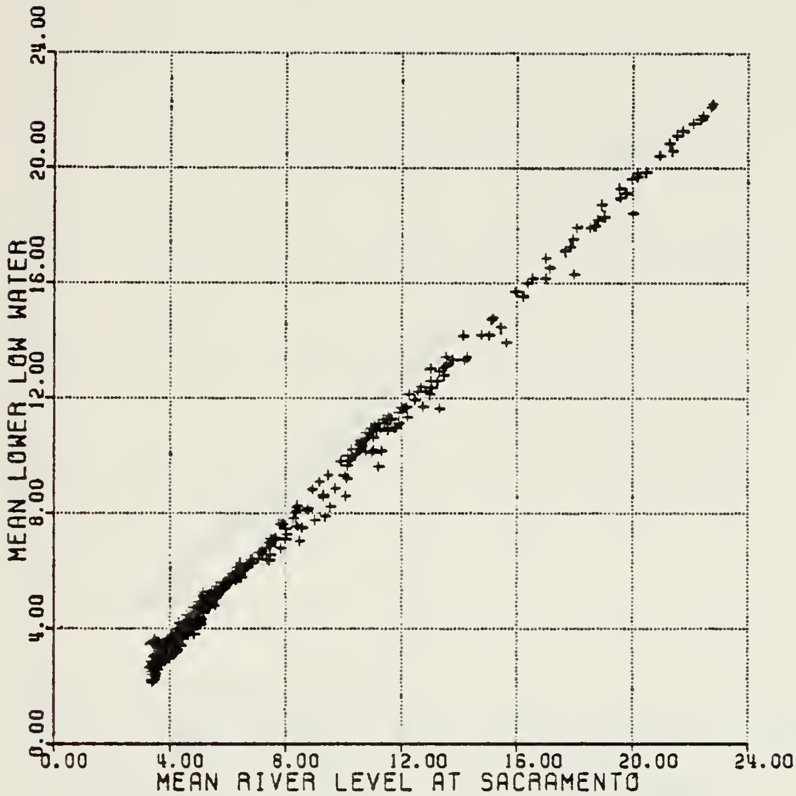
Graph W-10



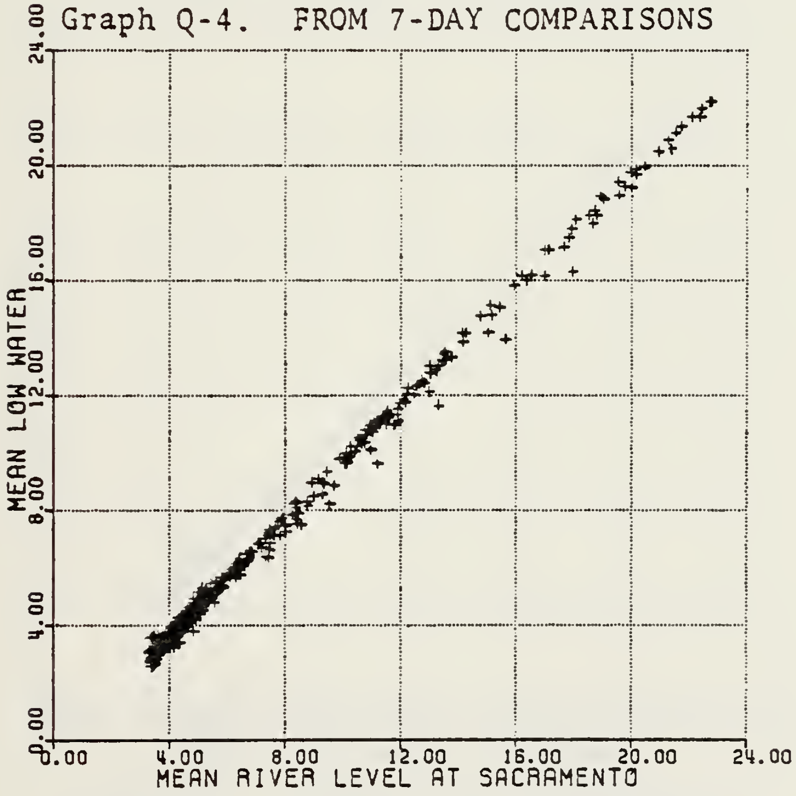
Graph W-11



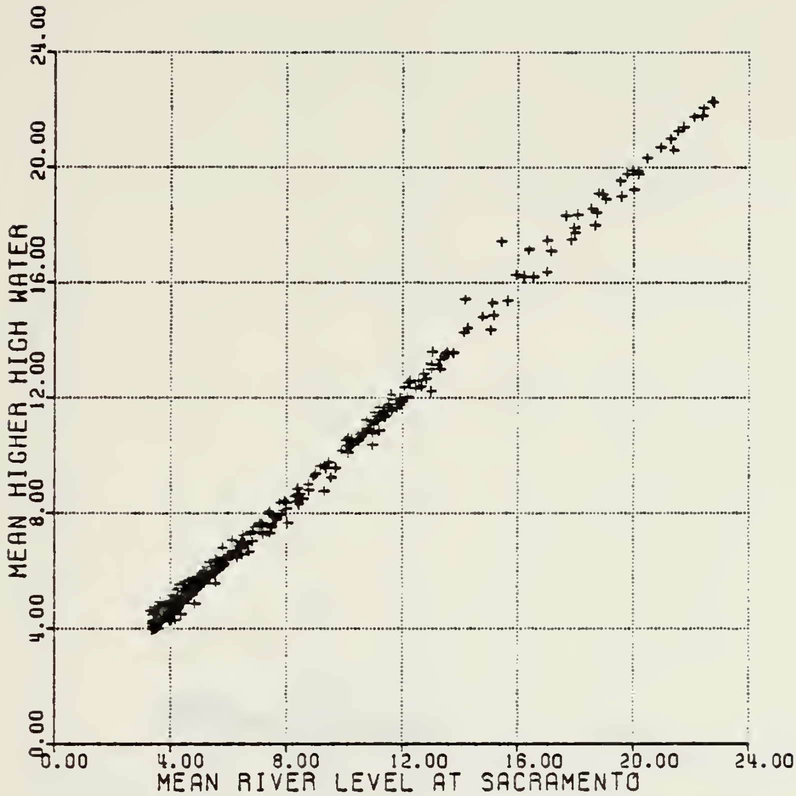
Graph Q-3. FROM 7-DAY COMPARISONS



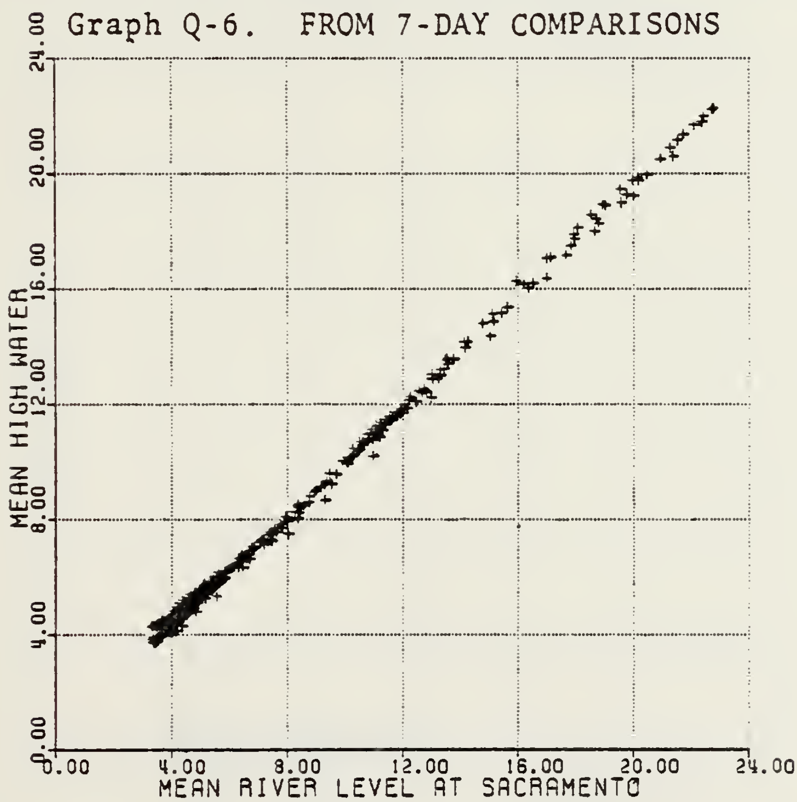
Graph Q-4. FROM 7-DAY COMPARISONS



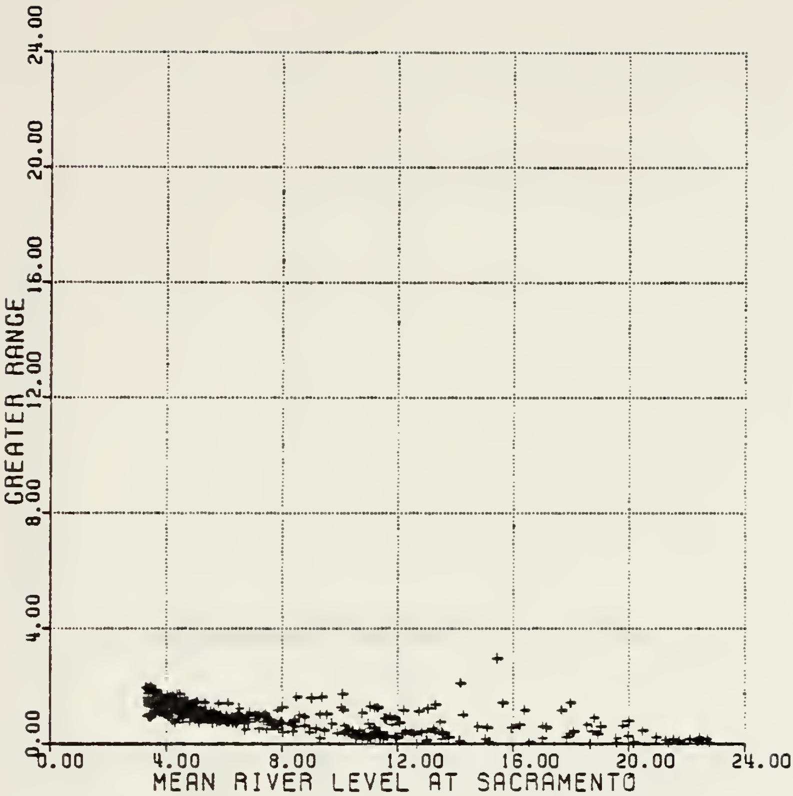
Graph Q-5. FROM 7-DAY COMPARISONS



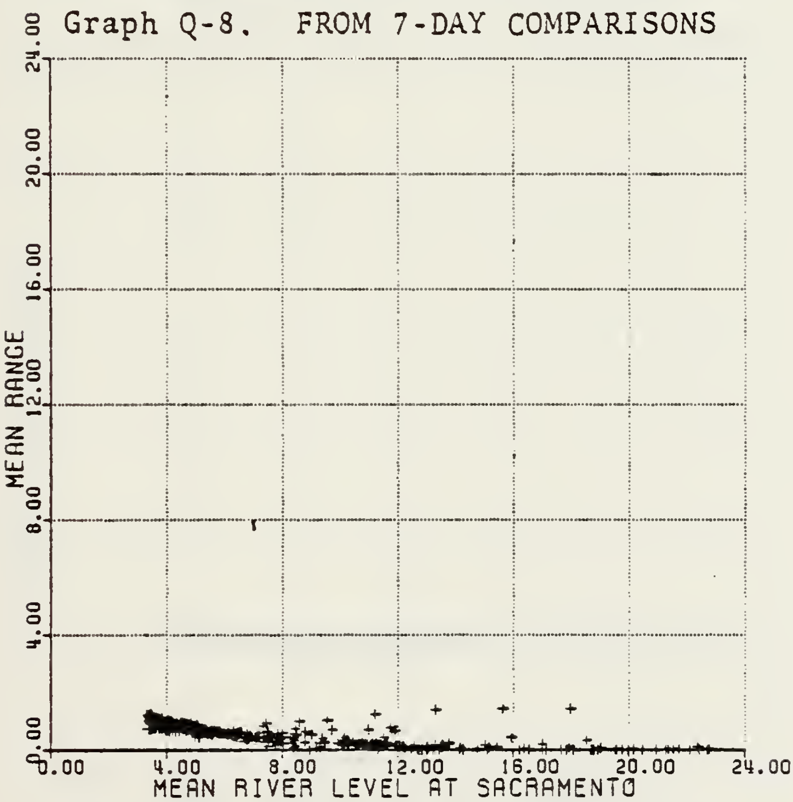
Graph Q-6. FROM 7-DAY COMPARISONS



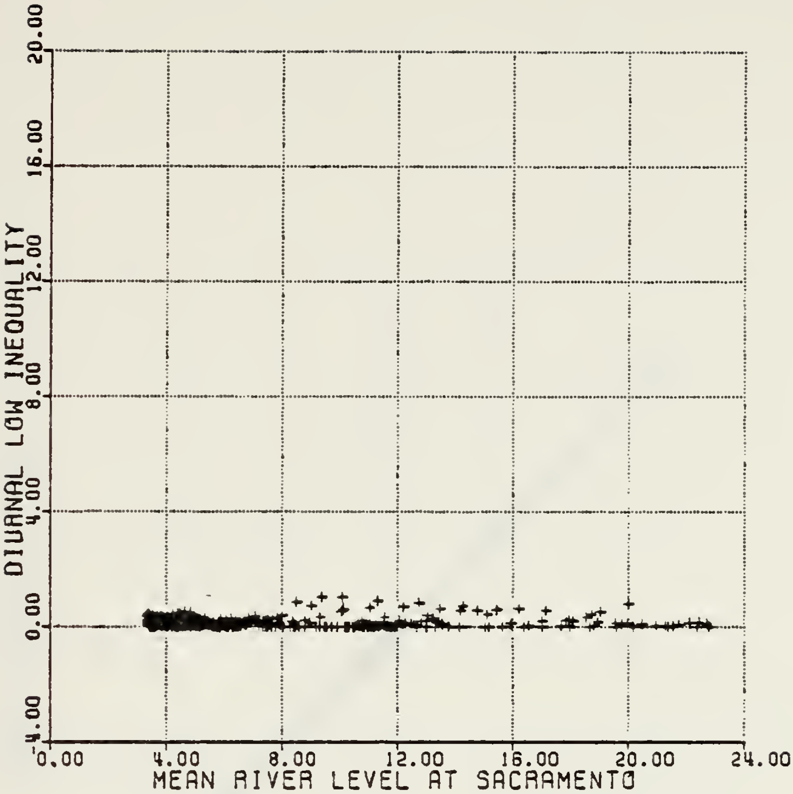
Graph Q-7. FROM 7-DAY COMPARISONS



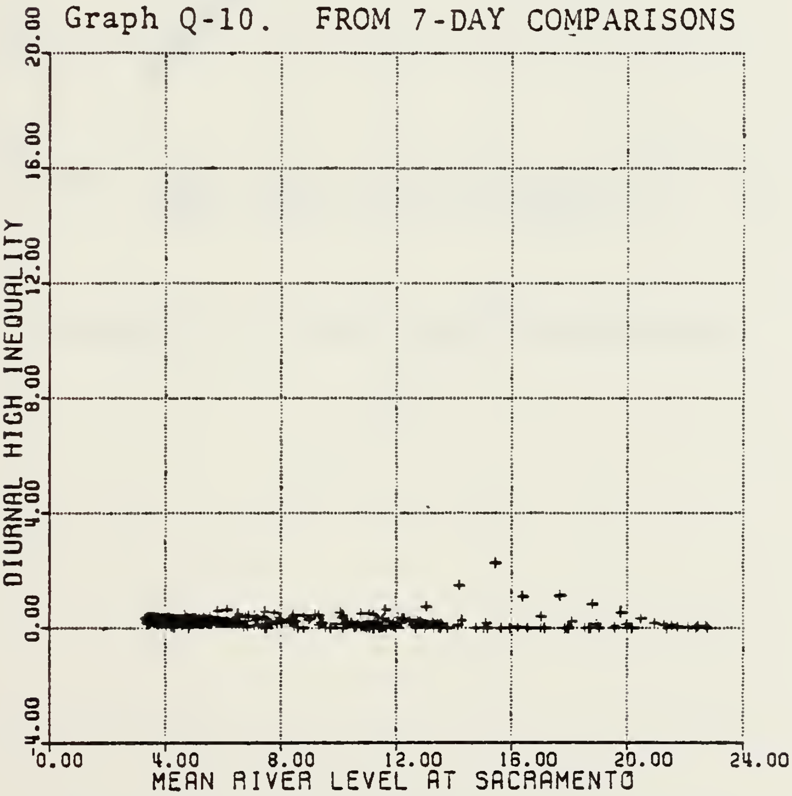
Graph Q-8. FROM 7-DAY COMPARISONS



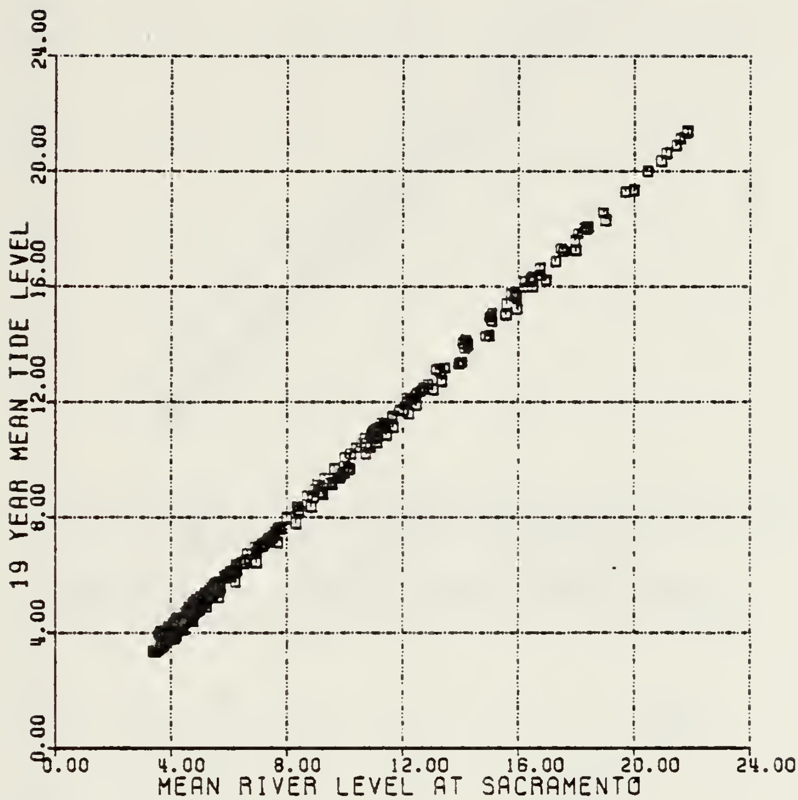
Graph Q-9. FROM 7-DAY COMPARISONS



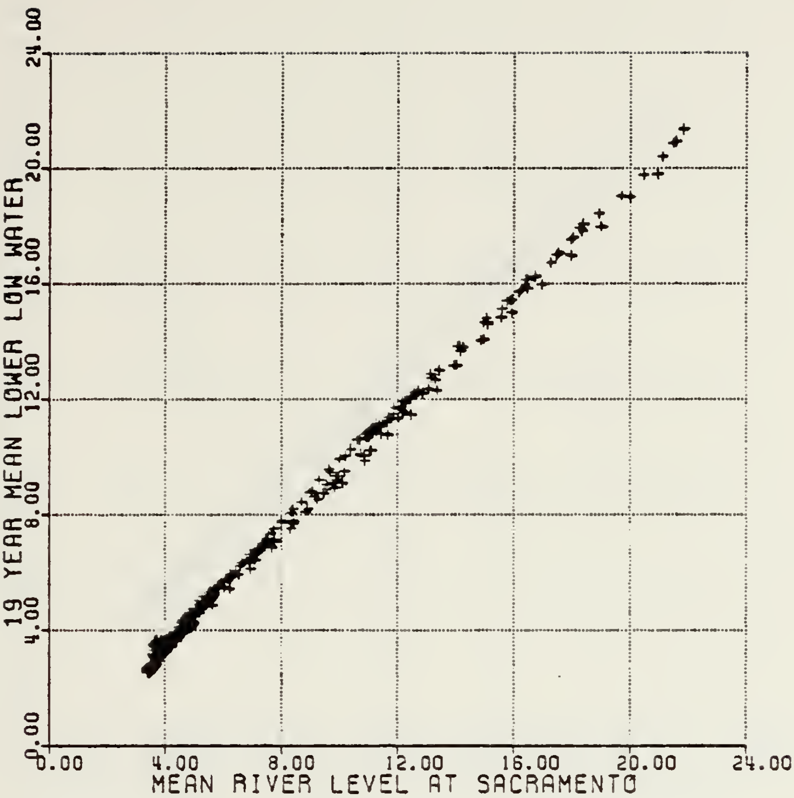
Graph Q-10. FROM 7-DAY COMPARISONS



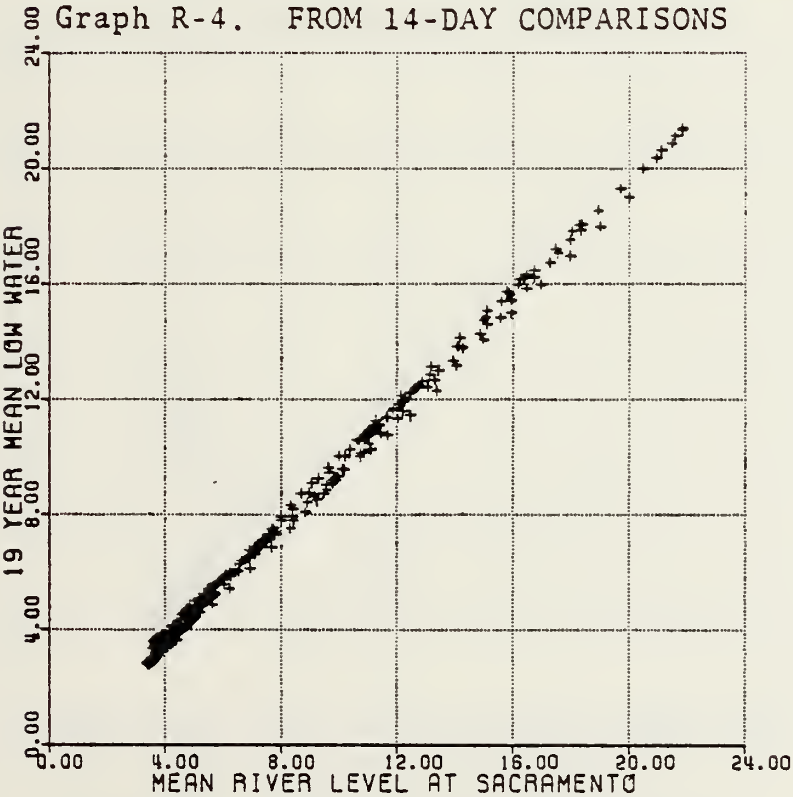
Graph Q-11. FROM 7-DAY COMPARISONS



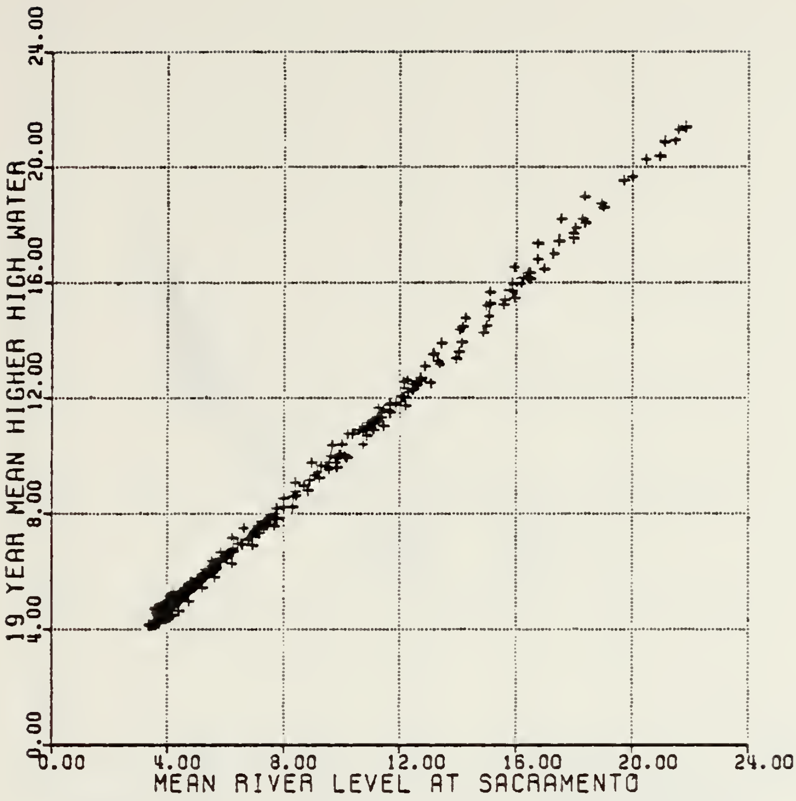
Graph R-3. FROM 14-DAY COMPARISONS



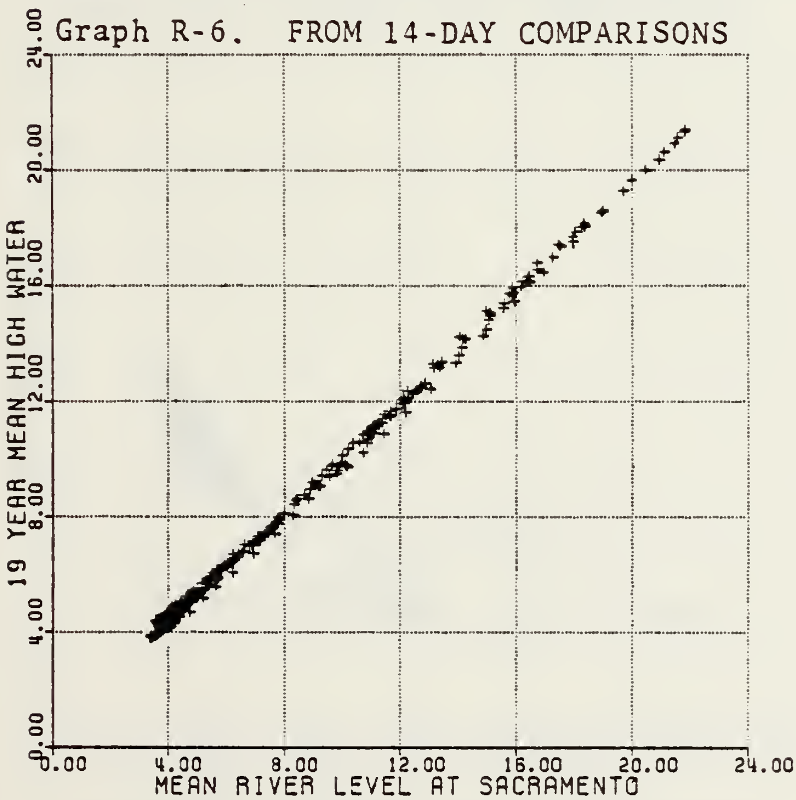
Graph R-4. FROM 14-DAY COMPARISONS



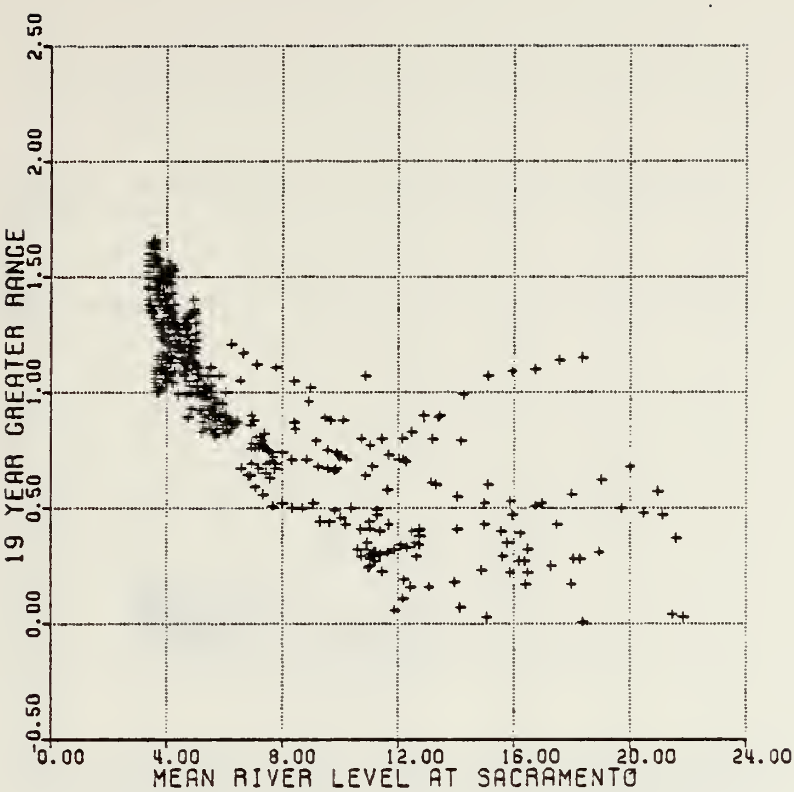
Graph R-5. FROM 14-DAY COMPARISONS



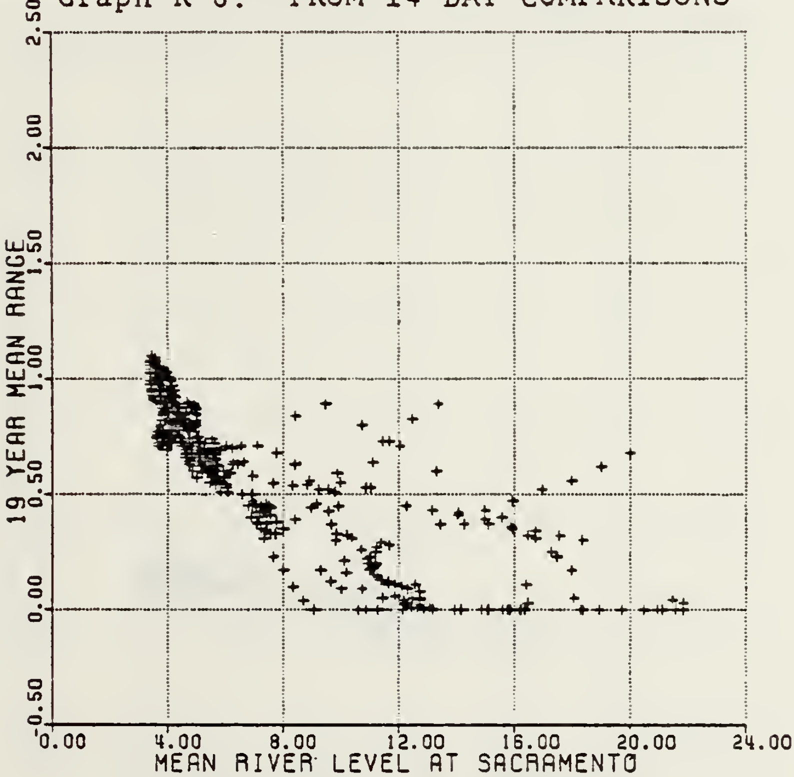
Graph R-6. FROM 14-DAY COMPARISONS



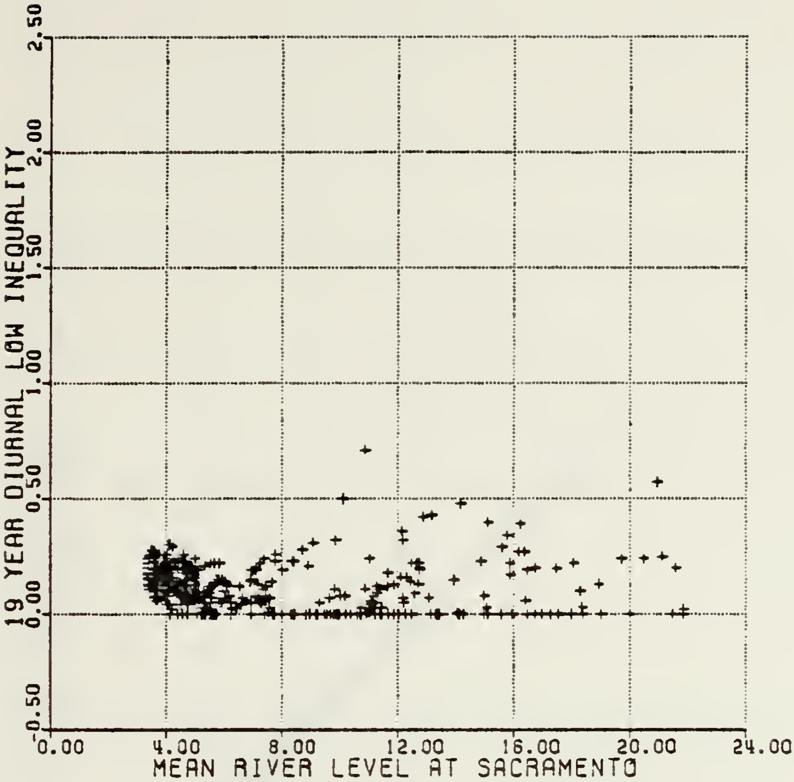
Graph R-7. FROM 14-DAY COMPARISONS



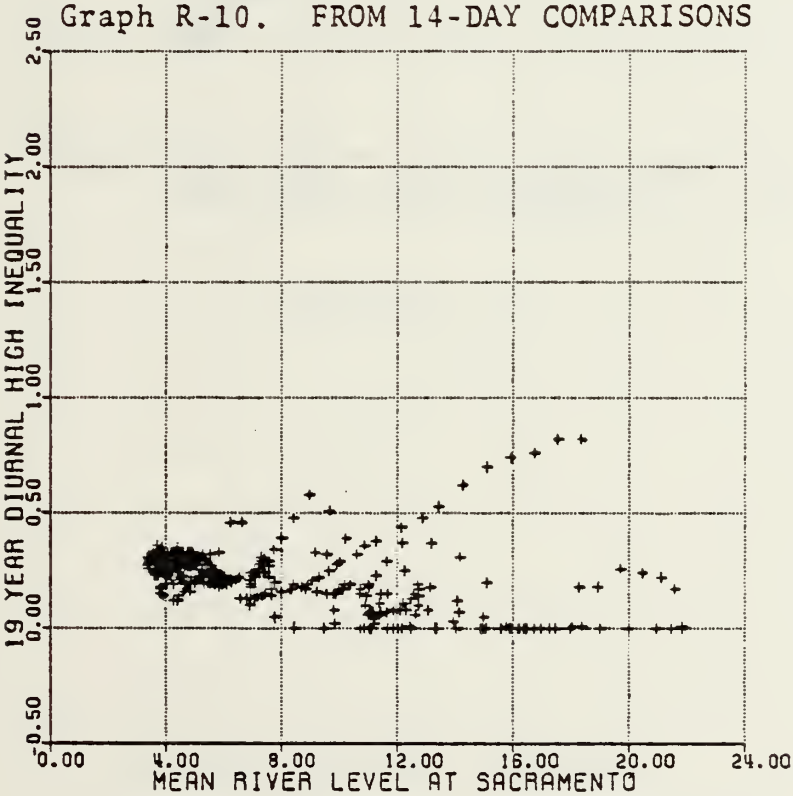
Graph R-8. FROM 14-DAY COMPARISONS



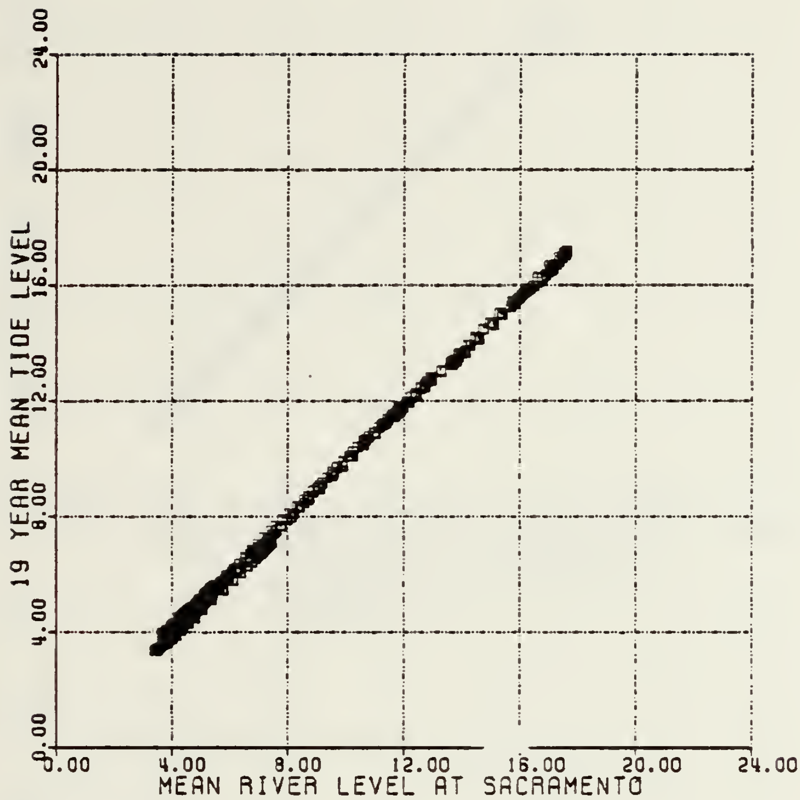
Graph R-9. FROM 14-DAY COMPARISONS



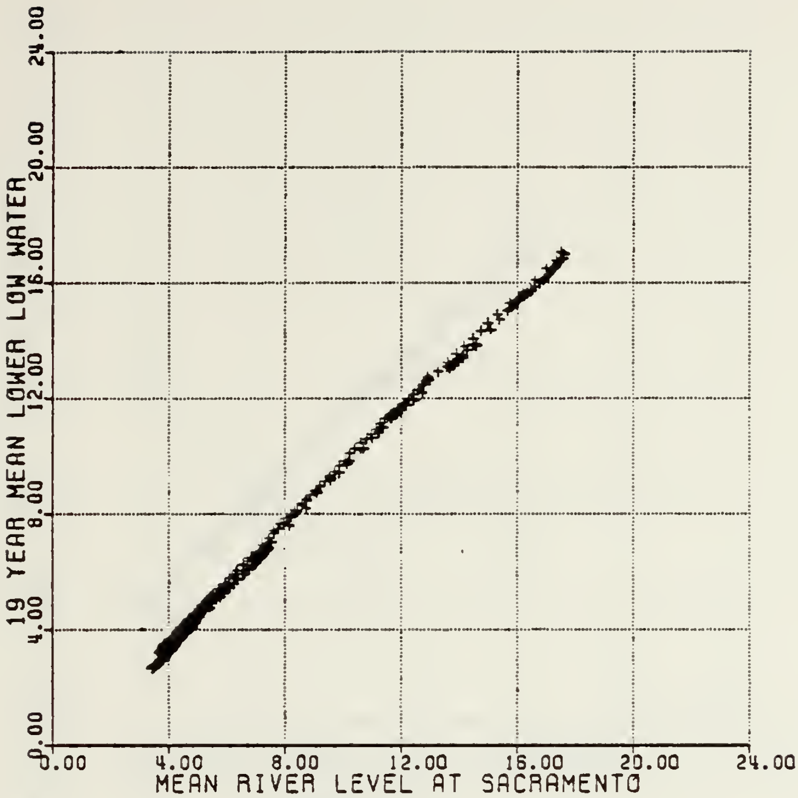
Graph R-10. FROM 14-DAY COMPARISONS



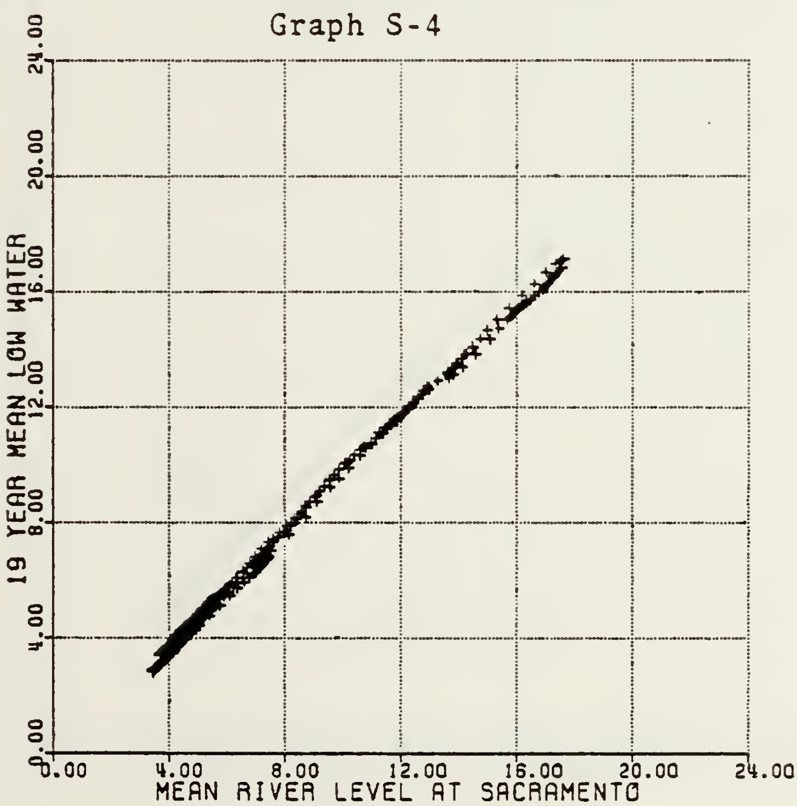
Graph R-11. FROM 14-DAY COMPARISONS


19 YEAR MEAN TIDE LEVEL
0.00
4.00
8.00
12.00
16.00
20.00
24.00
MEAN RIVER LEVEL AT SACRAMENTO
0.00
4.00
8.00
12.00
16.00
20.00
24.00

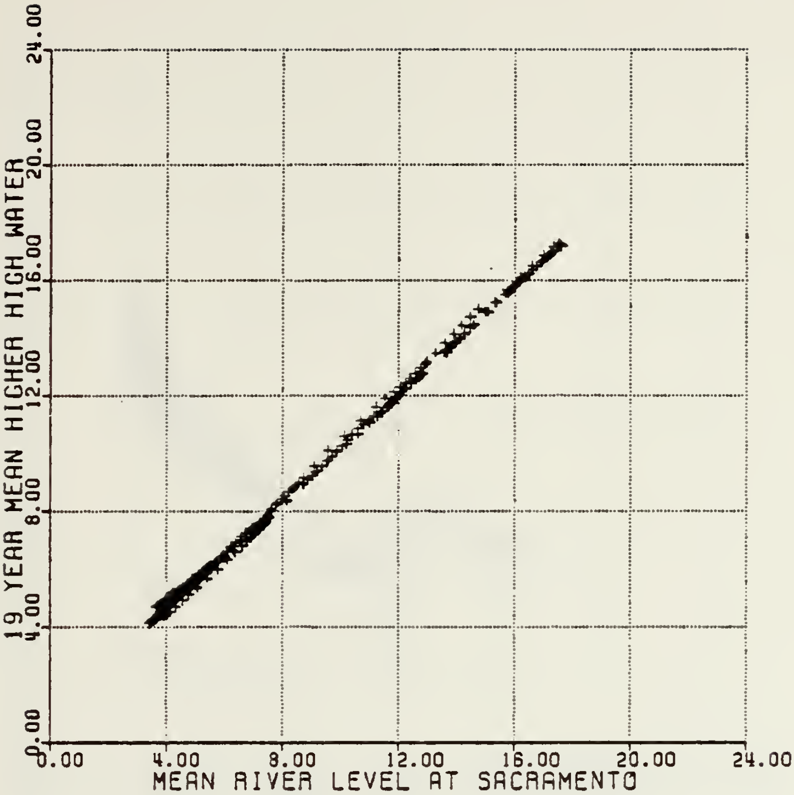
Graph S-3



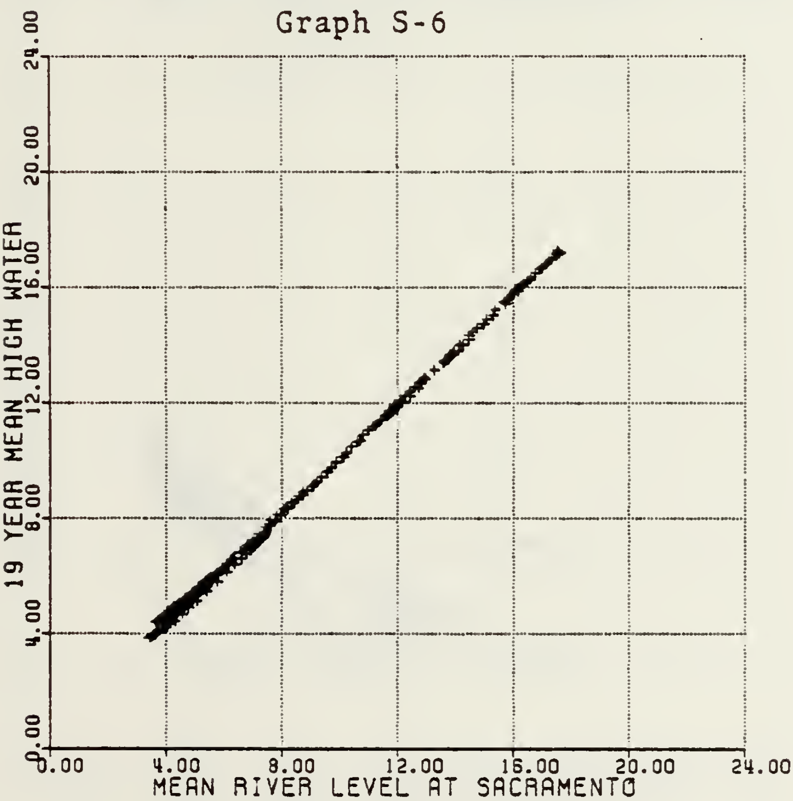
Graph S-4



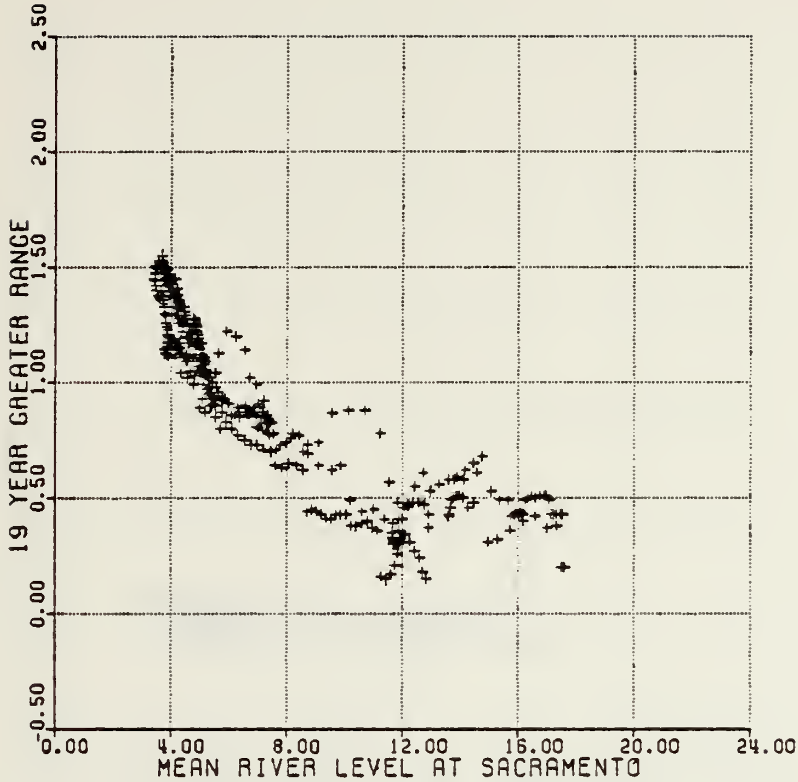
Graph S-5



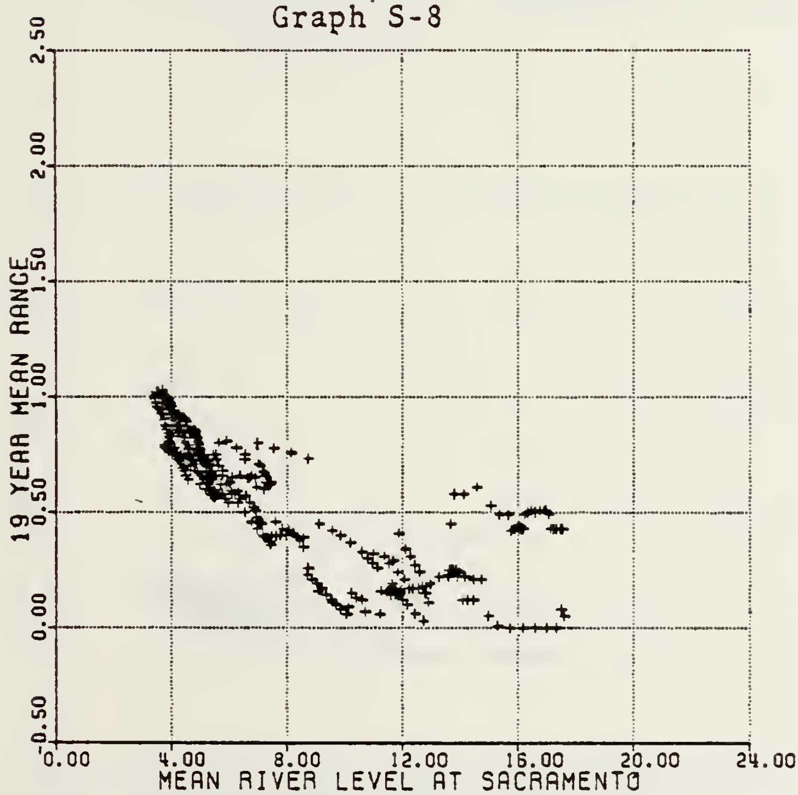
Graph S-6



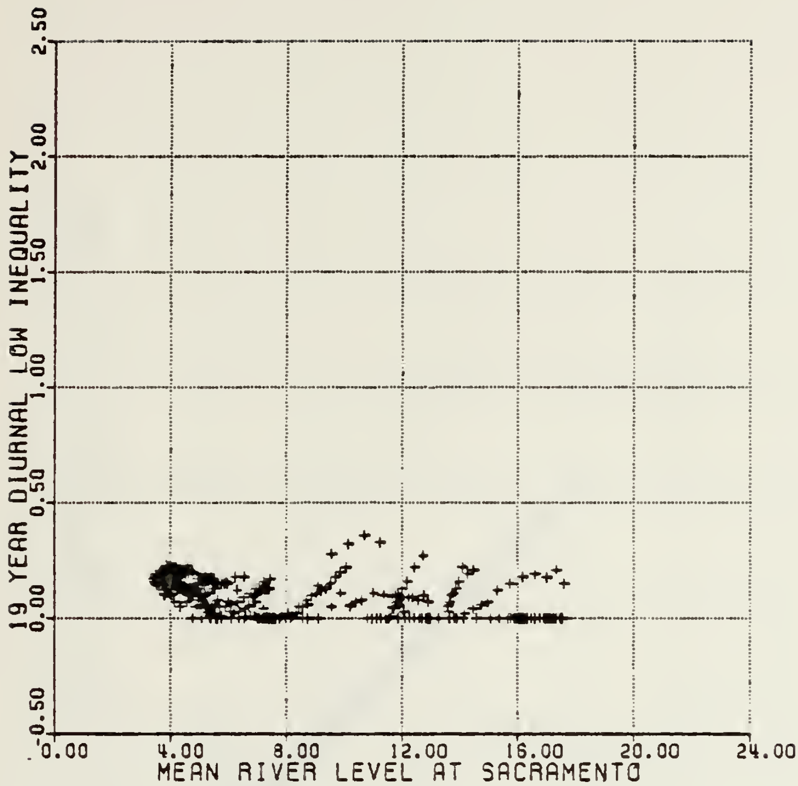
Graph S-7



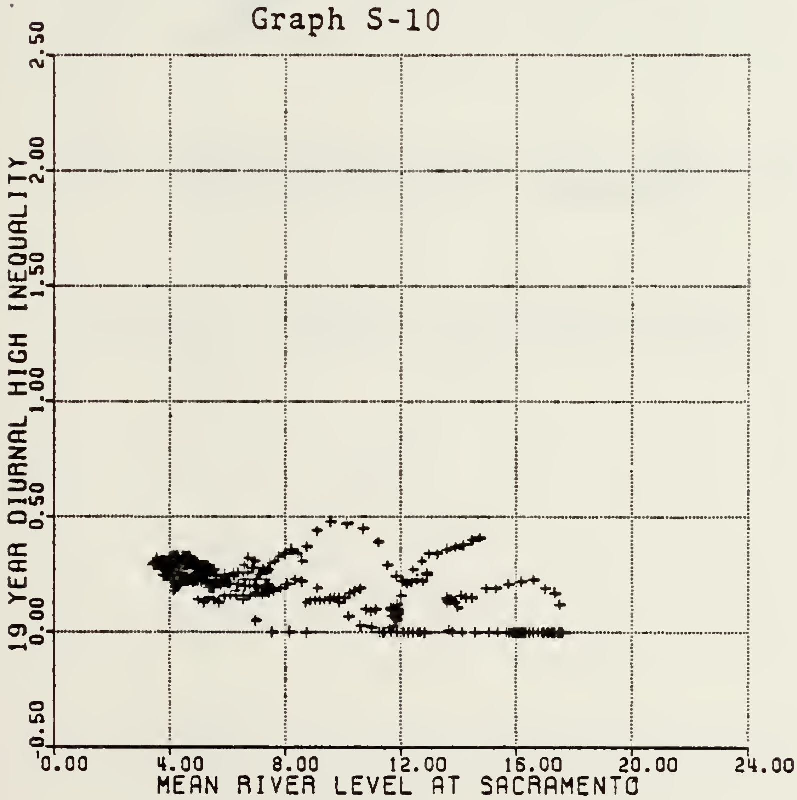
Graph S-8



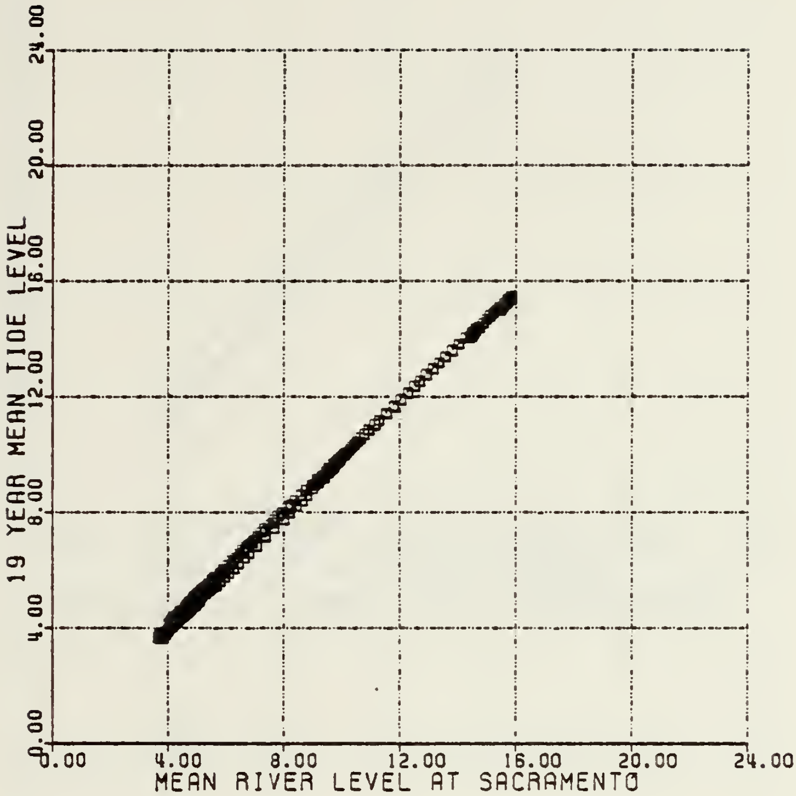
Graph S-9



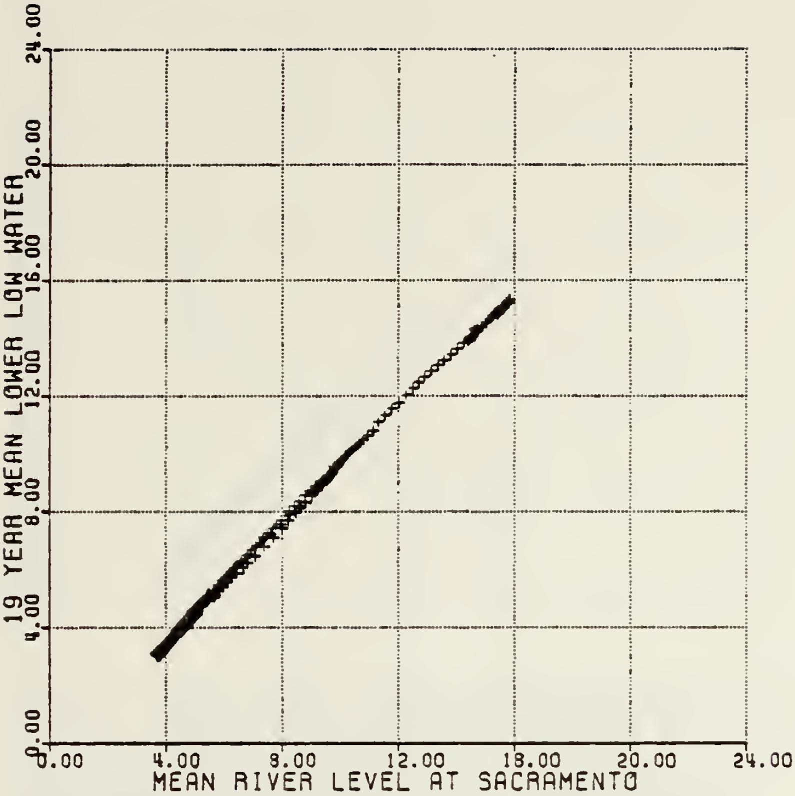
Graph S-10



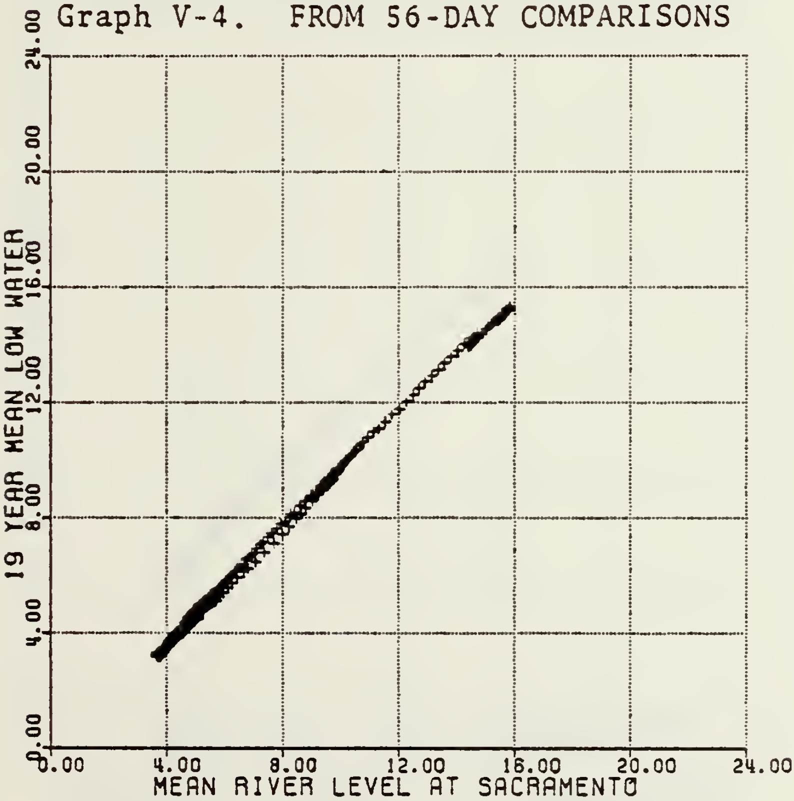
Graph S-11



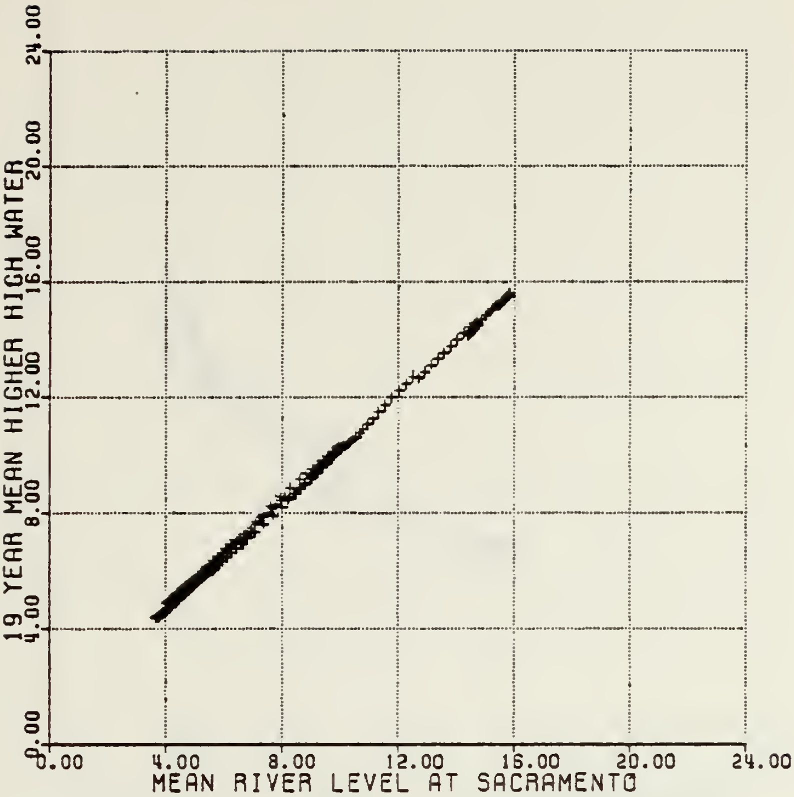
Graph V-3. FROM 56-DAY COMPARISONS



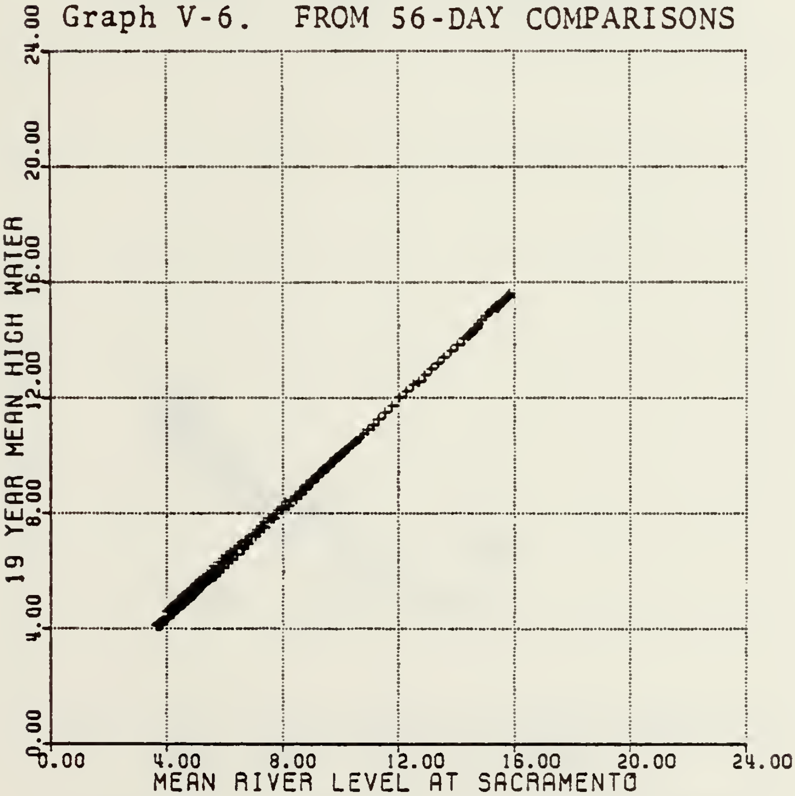
Graph V-4. FROM 56-DAY COMPARISONS



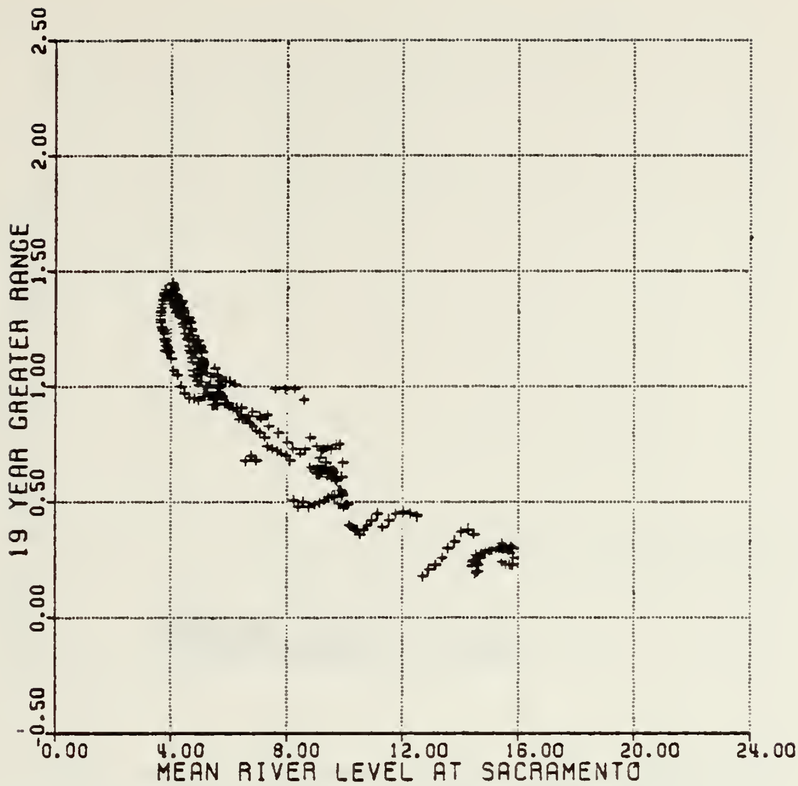
Graph V-5. FROM 56-DAY COMPARISONS



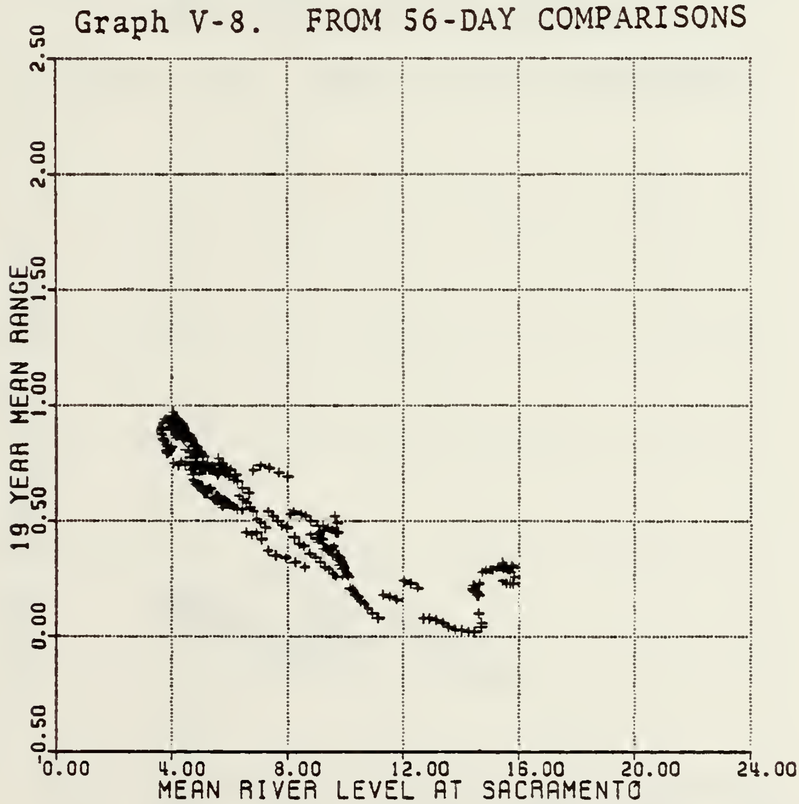
Graph V-6. FROM 56-DAY COMPARISONS



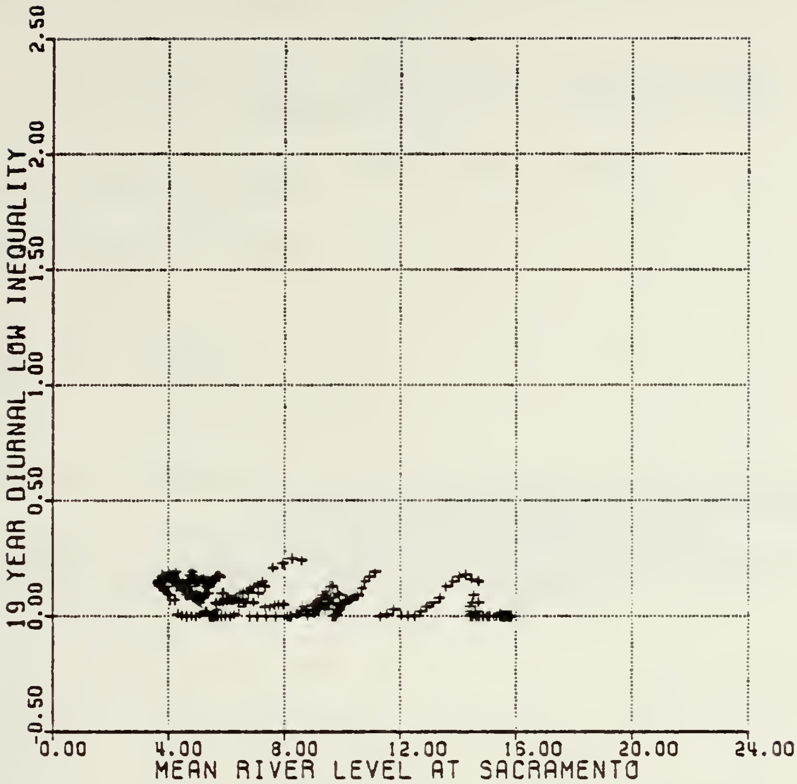
Graph V-7. FROM 56-DAY COMPARISONS



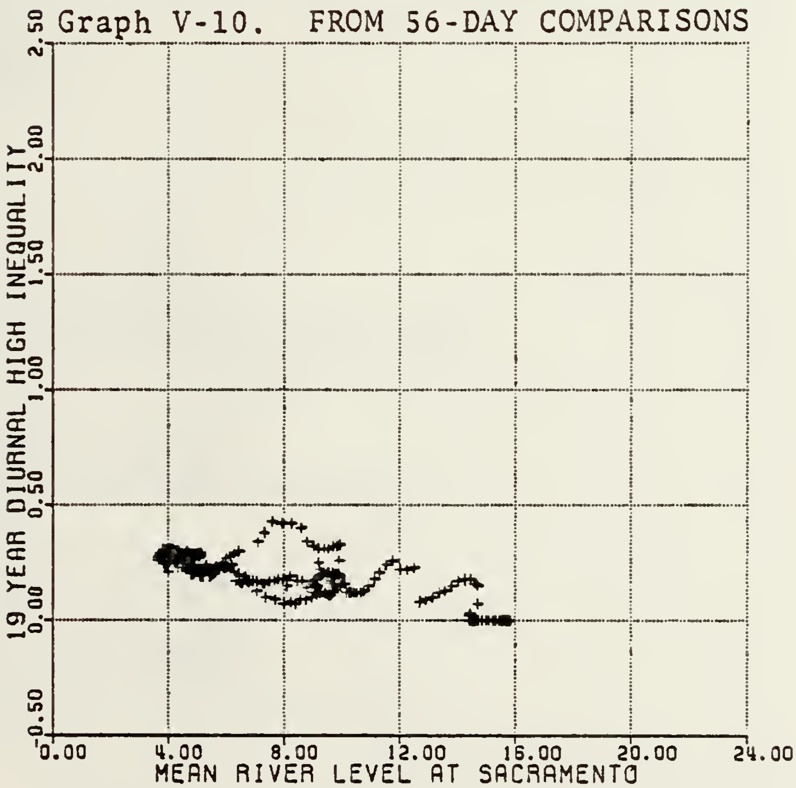
Graph V-8. FROM 56-DAY COMPARISONS



Graph V-9. FROM 56-DAY COMPARISONS



Graph V-10. FROM 56-DAY COMPARISONS



Graph V-11. FROM 56-DAY COMPARISONS

APPENDIX B

```
SUBROUTINE TO COMPUTE 19 YEAR TIDAL DATUMS FROM A
COMPARISON OF SIMULTANEOUS TIDES AT A SUBORDINATE
STATION FROM PRESIDIO EPOCH 1960-1978

HT1,HT2,TM1,TM2 ARE SYNCRONIZED ARRAYS OF HEIGHTS
AND TIMES OF HIGH AND LOW WATERS FOR PRESIDIO AND
THE SECONDARY STATION RESPECTIVELY

ITYPE IS AN ARRAY OF THE TYPE OF EACH TIDE
(1=HHW,2=LHW,3=HLW,4=LHW)

D = DIFFERENCE OF DIURNAL
H = HIGH OR HIGHER
L = LOW OR LOWER
M = MEAN
P = PRIMARY OR PRESIDIO
Q = INEQUALITY
S = SECONDARY OR SUBORDINATE
T = TOTAL
W = WATER

      SUBROUTINE COMPAR(HT1,TM1,HT2,TM2,ITYPE,SNGVD,NCOMP,LX
     1,                    MHHW,MHW,MTL,MLW,MLLW,CMN,CDHQ,CDLQ,
     2                    LOWPHS,HIPHS,PMTL,SMTL)
      DIMENSION HT1(232),HT2(232),TM1(232),TM2(232),ITYPE(23
      REAL*4 MHHW,MHW,MTL,MLW,MLLW,LOWPHS

INITIALIZE VARIABLES

      TPHHW=0.
      TPLHW=0.
      TPHLW=0.
      TPLLW=0.
      TSHHW=0.
      TSLHW=0.
      TSHLW=0.
      TSLLW=0.
      LOWPHS=0.
      HIPHS=0.
      A=0.
      B=0.
      C=0.
      D=0.

SORT BY TYPE OF TIDE

      DO 300 I=LX,NCOMP
      KTYPE=ITYPE(I)
      GO TO (310,320,330,340),KTYPE

SUM THE HIGHER HIGH WATERS

310   TPHHW=TPHHW+HT1(I)
      TSHHW=TSHHW+HT2(I)
      HIPHS=HIPHS+(TM2(I)-TM1(I))
      A=A+1.
      GO TO 299

SUM THE LOWER HIGH WATERS

320   TPLHW=TPLHW+HT1(I)
      TSLHW=TSLHW+HT2(I)
      HIPHS=HIPHS+(TM2(I)-TM1(I))
      B=B+1.
      GO TO 299
```

```
SUM THE HIGHER LOW WATERS

330   TPHLW=TPHLW+HT1(I)
      TSHLW=TSHLW+HT2(I)
      LOWPHS=LOWPHS+(TM2(I)-TM1(I))
      C=C+1.
      GO TO 299

SUM THE LOWER LOW WATERS

340   TPLLW=TPLLW+HT1(I)
      TSLLW=TSLLW+HT2(I)
      LOWPHS=LOWPHS+(TM2(I)-TM1(I))
      D=D+1.
299   CONTINUE
300   CONTINUE

COMPUTE THE DIFFERENCE TOTALS

      DHHW=TSHHW-TPHHW
      DLHW=TSLHW-TPLHW
      DHLW=TSHLW-TPHLW
      DLLW=TSLLW-TPLLW

COMPUTE THE MEAN DIFFERENCES

      DMHHW=DHHW/A
      DMLHW=DLHW/B
      DMHLW=DHLW/C
      DMLLW=DLLW/D
      DMHW=.5*(DMHHW+DMLHW)
      DMLW=.5*(DMHLW+DMLLW)
      DMTL=.5*(DMHW+DMLW)

COMPUTE THE MEAN HIGH AND LOW TIME LAGS

      LOWPHS=LOWPHS/(C+D)
      HIPHS=HIPHS/(A+B)

COMPUTE THE MEAN TIDES

      PMTL=(TPHHW+TPLHW+TPHLW+TPLLW)/(A+B+C+D)
      PMTL=PMTL-8.61
      DSHHW=TSHHW/A
      DSLHW=TSLHW/B
      DSHLW=TSHLW/C
      DSLLW=TSLLW/D
      SMHW=.5*(DSHHW+DSLHW)
      SMLW=.5*(DSHLW+DSLLW)
      SMTL=.5*(SMHW+SMLW)

COMPUTE THE MEAN RANGE AND INEQUALITIES

      SMN=SMHW-SMLW
      SDHQ=DSHHW-DSLHW
      SDLQ=DSHLW-DSLLW
      DMN=DMHW-DMLW
      DHQD=DMHHW-DMLHW
      DLQD=DMHLW-DMLLW

COMPUTE THE RANGE RATIOS

      RMN=SMN/(SMN-DMN)
      RDHQ=SDHQ/(SDHQ-DHQD)
      RDLQ=SDLQ/(SDLQ-DLQD)
```

```
COMPUTE 19 YEAR MEAN TIDE LEVELS
FROM PRESIDIC EPOCH 1960-1978

      MTL=8.95+(MTL-SNGVD
      CMN=4.10*RMN
      CDHQ=0.60*RDHQ
      CDLQ=1.55*RDLQ
      MLW=MTL-(.5*CMN)
      MLLW=MLW-CDLQ
      MHW=MTL+(.5*CMN)
      MHHW=MHW+CDHQ
      RETURN
```

```
SUBROUTINE TO COMPUTE A RUNNING MEAN FROM AN ARRAY OF DATA

NIN IS THE NUMBER OF MEMBERS IN THE INPUT ARRAY
LTH IS THE NUMBER OF ARRAY MEMBERS IN EACH MEAN VALUE
IDEC IS THE INCREMENT OF MEAN COMPUTATION
  ( IDEC=3, EVERY THIRD MEAN IS COMPUTED)
NOUT IS THE NUMBER OF MEMBERS IN THE OUTPUT ARRAY

      SUBROUTINE BOXCAR(SL,NIN,LTH,IDEC,NOUT)
      REAL*4 SL(6200)
      NOUT=0
      ISTART=1
 20   IEND=ISTART+LTH-1
      IF(IEND.GT.NIN)RETURN
      SUM=0.
      DO 30 I=ISTART,IEND
 30   SUM=SUM+SL(I)
      NOUT=NOUT+1
      SL(NOUT)=SUM/FLOAT(LTH)
      ISTART=ISTART+IDEC
      GO TO 20
      RETURN
```

```
      THIS SUBROUTINE COMPUTES THE HEIGHTS AND TIMES OF HIGH AND
      LOW WATERS FROM AN ARRAY GTIDE OF HOURLY HEIGHTS

      LE IS THE NUMBER OF MEMBERS IN GTIDE
      HEIGHT IS AN ARRAY OF HEIGHTS
      TIME IS AN ARRAY OF TIMES IN HOURS AND HUNDREDTHS
      CTIME IS AN ARRAY OF TIMES OF DAY IN HOURS AND MINUTES

      SUBROUTINE HWLW (GTIDE,LE,HEIGHT,TIME,CTIME)
      DIMENSION GTIDE(12500),HEIGHT(2400),
     1          TIME(2400),CTIME(2400)
      KOLD=0
      J=0
      ID=1

      INITIAL GUESS OF HIGH OR LOW WATER

      DO 60 K=1,LE
      B=GTIDE(K)+GTIDE(K+1)-GTIDE(K+3)-GTIDE(K+4)
      IF(B)1,2,3
    1 IC=-1
      GO TO 4
    3 IC=1
    4 CONTINUE
      IF(ID+IC)60,5,60
    2 IC=-IC
    5 ID=IC

      FIT A SECOND ORDER CURVE TO THE HOURLY HEIGHTS

      J=J+1
      FZ=GTIDE(K)+4.*GTIDE(K+1)+9.*GTIDE(K+2)+16.*GTIDE(K+3)
     1+25.*GTIDE(K+4)
      FC=GTIDE(K)+GTIDE(K+1)+GTIDE(K+2)+GTIDE(K+3)
     1     +GTIDE(K+4)
      FL=GTIDE(K)+2.*GTIDE(K+1)+3.*GTIDE(K+2)+4.*GTIDE(K+3)
         +5.*GTIDE(K+4)

      COMPUTE HEIGHT AND TIME FROM THE EXTREMA OF THE CURVE

      A2=-(3./11.)*(((FZ-11.*FC)/6.)-(15.*FZ-55.*FL)/35.)
      A1=(FZ-11.*FC)/60.-((374./60.)*A2)
      A0=FC/5.-3.*A1-11.*A2
      TIME(J)=-A1/(2.*A2)
      HEIGHT(J)=A0+TIME(J)*A1+TIME(J)**2*A2
      TIME(J)=TIME(J)+FLOAT(K)-2.

      COMPUTE TIME IN HOURS AND MINUTES

      TEMPT=TIME(J)*100.
      TEMPT=.004*AMOD(TEMPT,100.)
      CTIME(J)=AMOD(TIME(J),24.)-TEMPT
   59 CONTINUE
   60 CONTINUE
      RETURN
```

LIST OF REFERENCES

Coast and Geodetic Survey, 1965, Manual of Tide Observations, U. S. Department of Commerce, Publication No. 31-1.

Godin, G., 1966, Daily Mean Sea Level and Short-Period Seiches, International Hydrographic Review, v. XLIII, No. 2, 1975.

Hicks, S. D., 1980, The National Tidal Datum Convention of 1980, Office of Oceanography, Tides and Water Levels Division, National Ocean Survey, May 1980 (unpublished).

Hydrographic Department Admiralty, Datums for Hydrographic Surveys, Admiralty Tidal Handbook No. 2, 1975.

Marmer, H. A., 1951, Tidal Datum Planes, U.S. Department of Commerce, Coast and Geodetic Survey, Special Publication No. 135.

National Ocean Survey, Tide Tables 1978, U.S. Department of Commerce.

Swanson, R. L., 1974, Variability of Tidal Datums and Accuracy in Determining Datums from Short Series of Observations, U.S. Department of Commerce, National Ocean Survey, NOS Tech. Rep. No. 64.

Zeile, F. C., 1979, Tidal and River Datums in the Sacramento River, Master's Thesis, Naval Postgraduate School, Monterey, June 1979.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, California 93940	2
3.	Chairman, Code 68 Department of Oceanography Naval Postgraduate School Monterey, California 93940	1
4.	Chairman, Code 63 Department of Meteorology Naval Postgraduate School Monterey, California 93940	1
5.	Department of Oceanography, Code 68 Naval Postgraduate School Monterey, California 93940	3
6.	Professor Warren C. Thompson, Code 68 Th Department of Oceanography Naval Postgraduate School Monterey, California 93940	5
7.	Library Scripps Institution of Oceanography P. O. Box 2367 La Jolla, California 92037	1
8.	SIO Library University of California, San Diego P. O. Box 2367 La Jolla, California 92037	1
9.	Department of Oceanography Library Oregon State University Corvallis, Oregon 97331	1
10.	Department of Oceanography Library University of Washington Seattle, Washington 98105	1

11.	Director Naval Oceanography Division Navy Observatory 34th and Massachusetts Avenue NW Washington, D.C. 20390	1
12.	Commander Naval Oceanography Command NSTL Station Bay St. Louis, Mississippi 39529	1
13.	Commanding Officer Naval Oceanographic Office NSTL Station Bay St. Louis, Mississippi 39529	1
14.	Director Naval Oceanography and Meteorology National Space Technology Laboratories NSTL Station, Mississippi 39529	1
15.	Commanding Officer Naval Ocean Research and Development Activity NSTL Station Bay St. Louis, Mississippi 39529	1
16.	Oceanographer of the Navy Naval Oceanography Division (OP952) Navy Department Washington, D.C. 20350	1
17.	Naval Oceanographic Office Library, Code 3330 Washington, D.C. 20373	1
18.	Office of Naval Research, Code 410 NORDA NSTL Station, Mississippi 39529	1
19.	Coastal Engineering Research Center Kingman Building Fort Belvoir, Virginia 22060 ATTN: Dr. D. Lee Harris Library	2

20. Library 1
Waterways Experiment Station
U.S. Army Corps of Engineers
P. O. Box 631
Vicksburg, Mississippi 39180

21. Commanding Officer 1
U.S. Army Corps of Engineers
Sacramento District Office
Sacramento, California 95814

22. Mr. Jan Stevens, Assistant Attorney General 1
California Department of Justice
555 Capitol Mall
Sacramento, California 95814

23. Mr. N. Gregory Taylor, Assistant Attorney General 1
California Department of Justice
3580 Wilshire Boulevard
Los Angeles, California 90010

24. California Department of Justice 2
State Building, Room 6000
San Francisco, California 94102

ATTN: Mr. Bruce S. Flushman, Dep. Atty. Gen.
Mr. John Briscoe, Dep. Atty. Gen.

25. California State Lands Commission 5
1807 13th Street
Sacramento, California 95814

ATTN: Mr. William Northrop, Executive Officer
Mr. F. D. Uzes, Super. Bdry. Det. Off.
Mr. James N. Dowden, Bdry. Det. Off.
Mr. Donald J. Brittnacher, Sr. Bdry. Det. Off.
Mr. Jack Rump, Staff Counsel

26. Mr. Richard Oltman 1
U.S. Geological Survey
2800 Cottage Way, R
Sacramento, California 95825

27. Mr. R. A. Baltzer 1
U. S. Geological Survey
Water Resources Division
Reston, Virginia 22092

28. Director (Code PPH) 1
Defense Mapping Agency
Bldg 56, U.S. Naval Observatory
Washington, D.C. 20305

29. Director (Code HO) 1
Defense Mapping Agency Hydrographic/
Topographic Center
6500 Brookes Lane
Washington, D.C. 20315

30. Director (Code PSD-MC) 1
Defense Mapping School
Ft. Belvoir, Virginia 22060

31. Mr. Timothy A. Bouquet (Code HYH2) 3
DMA Hydrographic/Topographic Center
6500 Brookes Lane
Washington, D.C. 20315

32. RADM Herbert R. Lippold Jr., Director 1
National Ocean Survey
6001 Executive Boulevard
Rockville, Maryland 20852

33. Chief, Program Planning and Liaison (NC-2) 1
National Oceanic and Atmospheric
Administration
Rockville, Maryland 20852

34. Mr. Carrol I. Thurlow 1
Assistant to the Chief Scientist CX4
National Ocean Survey
6001 Executive Boulevard
Rockville, Maryland 20852

35. Office of Oceanography 9
National Ocean Survey
6001 Executive Boulevard
Rockville, Maryland 20852

ATTN: CAPT Wesley V. Hull C21
Kathleen H. Anderson C21
Dr. Henry R. Frey C21
Mr. Samuel E. McCoy C21
Mr. Charles R. Muirhead C211
Mr. Donald C. Simpson C212
Mr. Elmo E. Long C212
Mr. Richard C. Patchen C2111
Mr. Bruce B. Parker C2112

36. Tides and Water Levels Division 15
Office of Oceanography
National Ocean Survey
6001 Executive Boulevard
Rockville, Maryland 20852

ATTN: CDR Ralph J. Land C23 (3 copies)
Dr. John M. Diamante C23
LCDR Donald Spillman C231
Doug Martin C231
Robert P. Masterson C231
Mr. Stephen K. Gill C231
Mr. Howard V. Krishner C231
Mr. Jack E. Francher C232
Mr. Jim R. Hubbard C233
Mr. Raymond A. Smith C233
Mr. Donald D. Carrier, Jr., C233
Mr. William M. Stoney C233
Mr. Steacy D. Hicks C2X6

37. Director 1
Pacific Marine Center NOAA
1801 Fairview Avenue East
Seattle, Washington 98102

38. Director 1
Atlantic Marine Center NOAA
439 West York Street
Norfolk, Virginia 23510

39. CDR Donald E. Nortrup 1
NOAA Ship Peirce
439 West York Street
Norfolk, Virginia 23510

Thesis 190195
B7348 Bouquet
Precision of tidal
datums in the Sacra-
mento River, California.